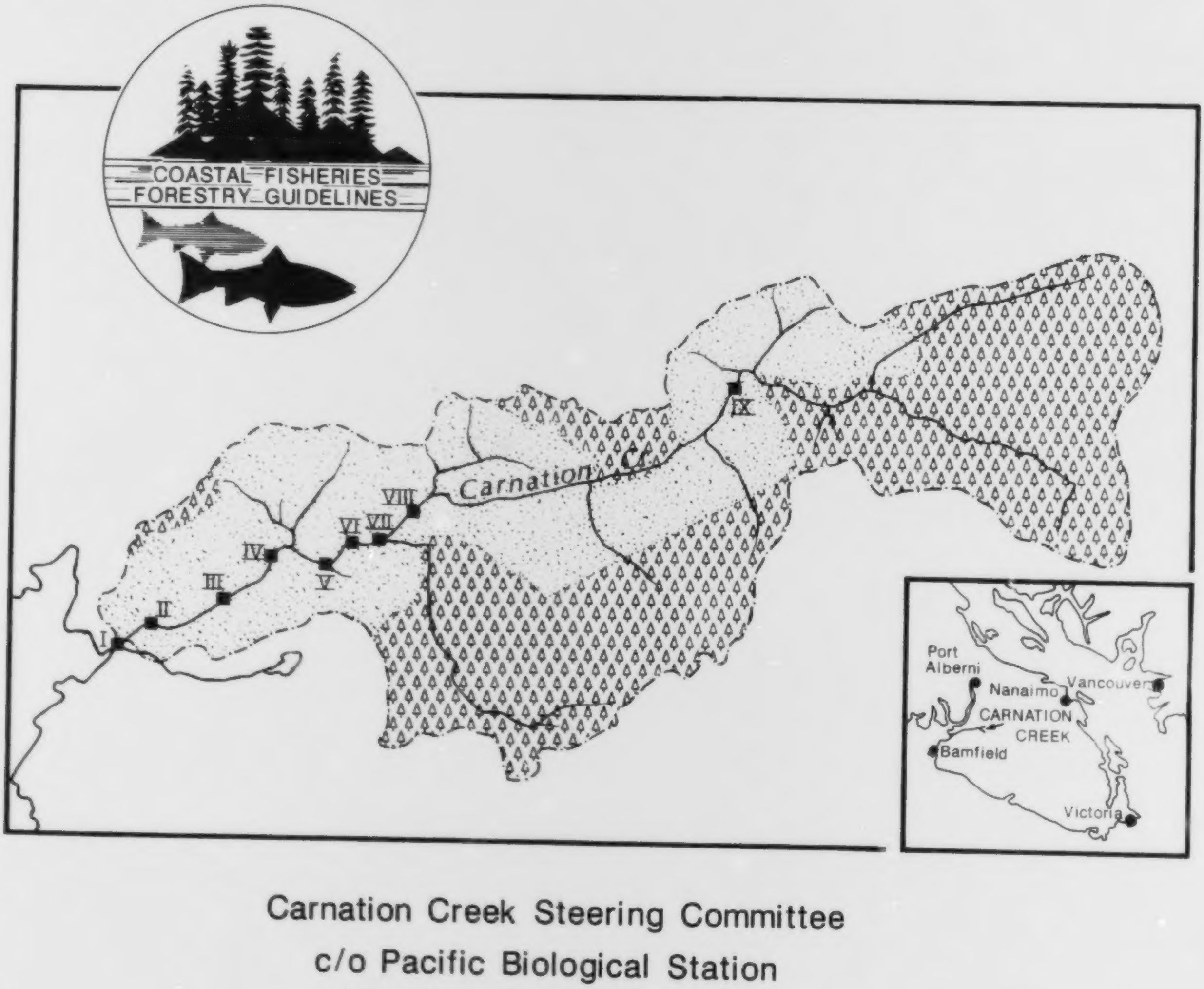
Proceedings of the Workshop:

Applying 15 Years of CARNATION CREEK Results

T.W. Chamberlin, Ed.



Carnation Creek Steering Committee
c/o Pacific Biological Station
Nanaimo, British Columbia
Canada V9R 5K6

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T.W. Chamberlin, Editor

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FOREWORD

This proceedings, representing 17 years of results from the Carnation Creek watershed study, contains 17 technical papers about the physical and biological processes of the Carnation Creek ecosystem. These papers represent the scientist's viewpoint of results and their implications.

After each session of technical papers, the proceedings contain thoughtful commentaries from 6 panels of fish and forest agency staff and forest industry representatives. These commentaries present the practical, and often blunt, opinions of the usefulness of the technical papers in real life, with the final panel adding viewpoints from the United States perspective.

Finally, the verbatim questions and answers of the audience to each session of technical papers and panelists are also included so that the extent of understanding or uncertainties is preserved. I hope that readers will carefully examine these audience comments. Our plans for the future as scientists and managers must rest on the reality of actual communication, not what we think people "ought to know". Appendix 1 contains additional comments on this topic by Gordon Hartman.

The technical papers summarize an enormous range of new knowledge, ranging from upstream water and sediment transport processes to consequences in the estuary environment. They also illustrate large gaps in our knowledge such as the necessary recovery time for disturbed alluvial channel stabilization and valley bottom groundwater levels. If anything, the Carnation Creek experience has confirmed that 17 years is indeed a very short time span with respect to documenting the cumulative effects of forest harvesting on a small, relatively stable coastal watershed. The synthesis by Gordon Hartman in the final session underscores the care we must take in drawing apparently "simple" conclusions.

During the months following this workshop, I have had the privilege of helping implement the British Columbia Coastal Fisheries/Forestry Guidelines. These guidelines were developed through a cooperative process of reviewing research and management experience by both agencies and the forest industry, and are being implemented through intensive cooperative training workshops.

This process has been credible and successful largely because of the foundation of knowledge gained in the Carnation Creek study, and because of the honest involvement and feedback from field level practitioners. I know of no other way in which research can be usefully planned and usefully applied, and sincerely hope that these proceedings will continue that process.

Finally, I must caution readers that although the proceedings try and preserve the flavor and content of panel and audience remarks, some editing of the verbatim transcript was necessary, and the editor takes full responsibility for errors which may have been introduced.

Many people provided considerable and patient support for developing the workshop and these proceedings, but special thanks must be given to Lynn Halkett of MacMillan Bloedel Ltd. and Cathy Hohnsbehn of The Ministry of Environment and Parks. Their collaboration and energy was vital, and again demonstrates that integrated resource management depends on bringing people together; the resources are already integrated.

Tom Chamberlin,
Editor

WELCOME

W. Young
General Session Chairman

Welcome to the Carnation Creek Workshop. I sincerely appreciated the invitation to be General Session Chairman. I also appreciate that through my position with the B.C. Forestry Association, and not wearing the hat of a Government agency or of the forest industry or of an academic institution, I am now looked upon as being relatively "harmless" and thus get invitations to chair meetings that others may "fear to tread". In my naivete, I always accept. In fact, next week, I'm chairing a symposium on Native Land Claims in British Columbia.

I would be remiss if I did not acknowlege the support of the members of the Carnation Creek Steering Committee in organizing and arranging this workshop. While we'll leave the thanks to individuals until the concluding comments on Thursday, we should recognize the Steering Group's support and its members (and not necessarily in any order of importance):

Canada Dept. of Environment - Inland Waters Directorate

Recreational Fisheries Branch, B.C. Ministry of Environment & Parks

Council of Forest Industries

Canada Department of Fisheries and Oceans

MacMillan Bloedel Limited

Forest Service, B.C. Ministry of Forests and Lands

Canadian Forestry Service

While I appreciate that Charlie Scrivener will be describing the history of the Carnation Creek project itself, I'd like to develop a little history of my own. I especially want to do this since the objective of this workshop is to address technology transfer or applying Carnation Creek research results to Forest and Fisheries planning and operations.

I recall the first such workshop on Carnation Creek held here in Nanaimo some five years ago. I recall the event vividly since it was that event that led to Dave Narver providing me with a series of lectures over the succeeding month on "The Importance of Sculpins in Integrated Resource Planning in British Columbia".

During the coffee breaks at that first workshop, some of us discussed the need to incorporate these research results into the planning and operation phases as soon as possible. Consequently, a four-person Steering Committee was formed comprised of the forest industry, B.C. Ministry of Environment, Canada Department of Fisheries and Oceans and the B.C. Forest Service.

In April, 1983, a workshop was held in Parksville at which the strategy and content of the technology tranfser was agreed upon. (In fact, it was one of the more positive sessions that I had ever attended.) Guided by the four-man Steering Committee and supported by an able and knowledgeable Secretary, several small teams of field people (public land and private sectors) were put together to draft the guidelines.

Unfortunately and regrettably (in my opinion), the Steering Committee "disintegrated" at the eleventh hour before this drafting process could be completed--largely unavoidable disintegration due to early retirements, promotions to non-fisheries assignements and the like. In fact, only the DFO representative (the stalwart Forbes Boyd) remained out of the original foursome. That was some 2-1/2 years ago.

While I understand that the process of transferring Carnation Creek research results to operational plans is close to being finalized, it is with some distress that I recall that it was some five years ago that this process was put into place at the first Carnation Creek workshop.

So, let's hope that following this workshop we will see pertinent research results being applied to forestry and fisheries planning and operations--as the title of the workshop stipulates.

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THE CARNATION CREEK EXPERIMENTAL WATERSHED PROJECT: A DESCRIPTION AND HISTORY FROM 1970 TO 1986

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In 1970, the interest and concern of forest and fishery managers were growing rapidly about what impacts clear-cut logging practises were having on salmon stocks of Western North America. Logging practises were a major topic of a salmon and trout symposium in the H. R. MacMillan lecture series at the University of British Columbia in 1968 (Northcote 1969). The Alsea Watershed Study in the Douglas fir forests of Oregon was nearing completion and the results were presented and discussed in 1970 at another symposium at Corvallis, Oregon (Krygier and Hall 1971). Dr. D.W. Narver, then of federal fisheries, found that little detailed information was available from British Columbia or from cedar-hemlock watersheds. These old-growth forests are typical of coastal North America from the Olympic Peninsula in Washington State to southeast Alaska and the Queen Charlotte Islands (Krajina 1969). During the summer and autumn of 1970, fish populations were examined at a number of coastal streams, including Carnation Creek (Narver 1972; Narver and Andersen 1974). Later, funding levels restricted activities to a single watershed study with annual monitoring of summer fish populations at 4 other locations in Barkley Sound. The varied expertise which was required to quantify watershed processes influencing streams and their fish, was not available in federal fisheries. Therefore, other organizations such as B.C. Forest Service, B.C. Department of Environment, Canadian Forest Service, Environment Canada, B.C. Universities and MacMillan Bloedel Ltd. were asked to participate with us in a multi-disciplinary and long-term study at Carnation Creek.

WATERSHED DESCRIPTION

Carnation is a small watershed (10 km^2) which drains into Barkley Sound in the west coast of Vancouver Island (Fig. 1). Annual precipitation is 210-480 cm (Hetherington 1982), 75% of it falls between October and March, and 95% of it falls as rain. Stream flow is highly variable, ranging from .025 $m^3 \cdot s^{-1}$ in summer to 33 $m^3 \cdot s^{-1}$ during winter freshet. Peak flows of 37, 44, and 64 $m^3 \cdot s^{-1}$ with return periods of 5, 12, and 50 years, respectively have been observed during the study.

The topography of the basin features rugged terrain of steep slopes to 700 m elevation and a narrow valley bottom through which the stream meanders. The area has been heavily glaciated during the Pleistocene period. Slope soils are shallow, coarse textured and highly organic (Oswald 1973). Bedrock is mainly of volcanic origin. Soils in the valley bottom are derived from recent alluvium which is underlain by gravel deposits (as deep as 4 m), bedrock, and some silty clay deposits.

The pre-harvest vegetation and soils in the drainage were described at the 1982 workshop (Oswald 1982). The primary forest trees in the Carnation Creek drainage are western hemlock (*Tsuga heterophylla*), western red cedar (*Thuja plicata*), amabilis fir (*Abies amabilis*), Douglas fir (*Pseudotsuga menziesii*), Sitka spruce (*Picea sitchensis*), and red alder (*Alnus rubra*). The predominant shrubs were salal (*Gaultheria shallon*), stink current (*Ribes*

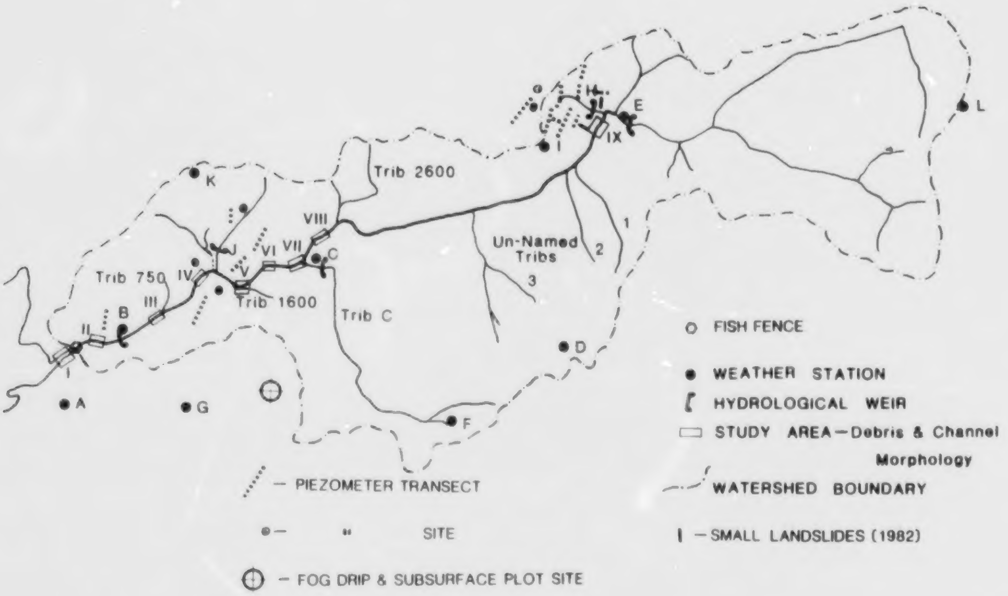

Figure 1. Locations of hydro-meteorological monitoring facilities and debris and channel morphology study sections within the Carnation Creek drainage.

bracteosum), salmonberry (*Rubus spectabilis*), and four species of *Vaccinium*.

Prior to logging, the main channel and tributaries were bordered by red alder, western red cedar and Sitka spruce. This canopy and its thick understory shaded the stream so that light intensities were one sixth of those of adjacent areas with no trees (de Leeuw 1982).

Anadromous fish utilize the lower 3.2 km of stream which contains study sections I to VIII (Fig. 1). Most chum salmon (*Oncorhynchus keta*) spawn in section I, while a few chum (3-25%), all coho salmon (*O. kisutch*), and all steelhead trout (*Salmo gairdneri*) prior to 1984 passed through the counting fence to spawn in areas represented by sections II to VIII (Fig. 1). In this segment of stream, mean gradient is 1.9% and the bed is characterized by gravel with few particles greater than 100 mm in diameter (Scrivener 1975). Numerous accumulations of fallen trees and buried logs occur in the channel. Extensive gravel bars indicate considerable gravel movement. From 3.2 to 4.1 km, the stream is confined to a narrow bedrock canyon with an average gradient of 8.4%. The channel contained numerous log-jams with gravel accumulations behind them when the project was initiated. The next 1.1 km of stream, 4.1 km to E weir (Fig. 1), flows over a gravel substrate with some cobbles (100-200 mm) and contains low numbers of resident cutthroat trout (*S. clarki clarki*). Study section IX is typical of this area (Fig. 1).

There are two types of tributaries to Carnation Creek, valley-wall tributaries and valley-floor (or wall-base) tributaries, as defined by Peterson and Reid (1984). The valley-wall tributaries, which include Tributaries C, J, and H, and three unnamed tributaries (Fig. 1), have gradients ranging from 16.5% to 49%. These tributaries descend all the way to Carnation Creek or descend for most of their length before crossing a short distance of flood plain. They contain bed rock and boulder bottoms and many fallen trees some of which store gravel. The valley-floor tributaries; Tributaries 750, 1600, and most of Tributary 2600 have gradients <1.5% and they are fed by groundwater and ephemeral seepage channels along the valley walls (Hartman et al. 1987). They flow among fallen trees and their beds are organic ooze which contain rooted aquatic plants (Brown 1985).

Some lower reaches contain sandy gravel bottoms. These valley-floor tributaries are used extensively by fish.

STUDY DESIGN AND LOGGING PLAN

The framework of objectives and study design of the Carnation Creek project was established by an inter-agency and industry working group of researchers. Approval and monitoring of its implementation were the responsibility of a steering committee of budget and policy managers. A project coordinator served as liaison and executive officer.

Study objectives included four general areas:

(1) To understand the major ecological and physical processes that influence salmon and trout populations in Carnation Creek;

(2) to determine how clearcut logging and forestry practises influence these processes and quantify the impacts on fish populations;

(3) to provide continuous input to managers developing resource management strategies for fisheries and forests; and

(4) to communicate results to the scientific/technical community and the general public. Objectives 3 and 4 involved publishing more than 95 articles or reports through a variety of media (Hartman and Scrivener, In prep.) and conducting two major workshops (Hartman 1982). Technical input to the new coast forest guidelines was continuous. Many presentations and watershed tours have been conducted for resource managers, scientists, students, politicians, and resource users during the last 16 years.

The project was initially planned to extend over three 5-year stages: a pre-logging monitoring stage -- 1971 to early 1975, a logging stage -- winter 1975/76 to 1979/80, and a post-logging stage -- spring 1980 to 1985. In 1975, a labour dispute forced a change in the logging plan. It increased the logging stage to 6 years (1976 to 1981), it delayed the post-logging stage (spring 1981 to spring 1986), and it extended the pre-logging period for most of the watershed until 1976 instead of 1975.

The six years of logging included 13 cutblocks in which 41% of the forest was removed (Fig. 2, Dryburgh 1982; Hartman et al. 1987). These low elevation watersheds were reserved for winter logging using "high lead systems" such as mechanical spars and grapple yarders. All logs were hauled by truck to sorting dumps and marine booming areas nearby. The cutblocks were burned, scarified, or left untreated. Then, tree seedlings were planted on the valley bottom and on the low gradient slopes during the spring following logging. The logging plan contained three basic treatments along the stream length that was available to salmon (Fig. 2).

1. Undisturbed streamside treatment - This area (sections II-IV) was logged as three openings during 1976 (23 ha), 1978/79 (19.4 ha), and 1980/81 (16 ha). This left the lower 1300 m of Carnation Creek with a variable width strip of deciduous vegetation and merchantable trees along its banks (Fig. 2).

2. Intense streamside treatment -- the second area included the next 900 m of stream (sections V and VI). It was logged in 1976/77 as two clearcuts (61,34.4 ha). Streamside alders were girdled and injected with Tordon 22K herbicide. All merchantable timber was felled away from the channel, or if leaning heavily, across it, and then yarded away from the stream to roadside landings. Streambanks and large debris in the channel were damaged. In 1977, this was no longer an acceptable logging practise along stream reaches that were used by salmon, but even today a few cutting permits are still being requested proposing an intense treatment (D. Morrison pers. comm.).

3. Careful streamside treatment -- the third area (section VIII) was logged as two clearcuts (63, 13 ha) during 1978/79. Minor vegetation such a salmonberry was left along the stream; only six merchantable trees that could not be jacked or cabled were felled across the channel and removed. Streamside alder was felled; and during scarification, the logging debris was piled for burning (Fig. 2). Now, this treatment is also no longer permitted along reaches that contain salmon, but it is proposed in many cutting permit requests.

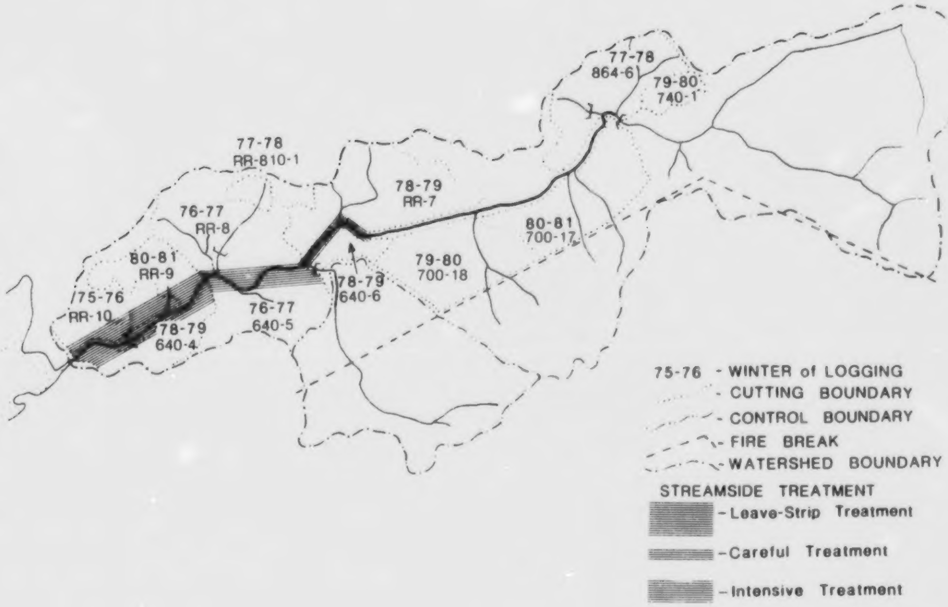

Figure 2. Cutblock locations, years of cutting and locations of leave strip, careful and intensive streamside treatment sections.

Road access was usually constructed one year prior to logging of a cutblock. Most roads were located well away from the main stream (Fig. 3) and the topography permitted full bench construction over most of their length. The single crossing of the creek was located 5 km upstream and immediately below E weir (Fig. 1 and 3). Ballast and surfacing materials consisted of hard and coarse gravel and blasted rock. Rock drilling equipment, Poclain shovels and D-8 cats were used during construction (Dryburgh 1982).

Upon completion of forest harvesting in May 1981, 41% of the drainage had been logged. Tributary C and the drainage above E weir (Fig. 1) were untreated and served as internal control watersheds. Tributary J was totally clearcut and slash burned during a 2-year period. Tributary H was clearcut, but logging slash was not broadcast burned (Fig. 1).

In early September 1984, portions of the watershed were aerially treated with the herbicide glyphosate. A microfoil boom and Bell-47 helicopter were used for the application. Results from these studies will be reported during another workshop.

COMPONENT STUDIES OF WATERSHED PROCESSES

Hydrometerological Processes

Weather records were obtained from 10 stations within the basin or at its perimeter (Fig. 1). Precipitation was measured at all of these sites, but temperature and humidity were recorded at only 4 of them. Wind data, barometric pressure, rain chemistry data, solar radiation, and evapotranspiration were also obtained at Station A (Fig. 1). The 10 sites were chosen to measure differences in precipitation due to sub-basin orientation, elevation and slope aspect. About 25% more precipitation was recorded at site F than site A. Water level was recorded at hydrological weirs on the main creek (B and E) and on 3 tributaries (C, H, and J; Fig. 1). Chart recordings were digitized for computer storage from which discharge was

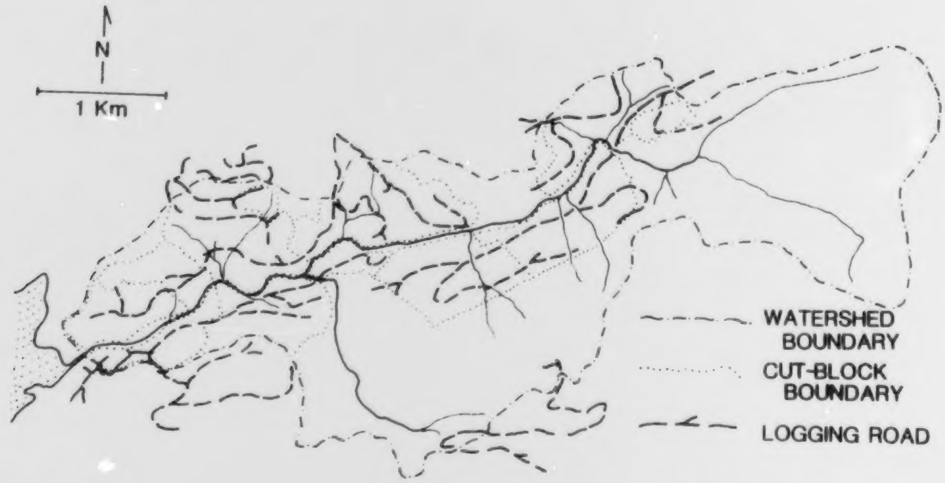

Figure 3. A map of Carnation Creek watershed showing cutblock boundaries and road layouts from the logging plan.

computed. Tables converting water level to stream flow were checked and updated every year with direct measurements at the weirs or from control cross sections nearby. Discharge patterns were compared among sub-basin treatments and through time (Hetherington 1982).

Changes of slope and of valley-bottom ground-water levels were recorded with 3 series of water level wells (piezometers; Fig. 1). They were located along transects in H and J watersheds and along the valley floor. Site comparisons were used to identify changes in water movement that were caused by roads, soil disturbance, or subbasin treatments.

Soil and Vegetation Disturbance and Recovery

Post-logging disturbance of soils and understory vegetation was assessed along transects and in plots (Fig. 4; Smith and Wass 1982; King and Oswald 1982). Cutblocks were surveyed before and after logging and after burning. Measurements of exposed mineral soil, of gouges, of slash, of exposed bedrock, of burned organic material and of slope angle were obtained at each site. This provided estimates of erosion and revegetation potential. The plots were used to determine revegetation rates and changes in plant communities including herbs, shrubs, and crop species. They were established and assessed within a year of logging or slash burning. Repeat assessments are being made 1, 2, 3, 5, 10, and 15 years thereafter.

Erosion, Transport, and Deposition Processes in the Stream

Measurements of suspended sediment transport were obtained at B weir with a battery powered pumping sampler (Fig. 1). Samples were pumped from a fixed point 10 cm above the bed at time intervals that were regulated by stream flow. During a number of freshets each year, these point samples were related to total stream transport by a series of depth integrated samples from various distances across the width of the channel. Sediment hydrographs were obtained in this manner from 1973 to 1986 (Anon 1973-84).

During road construction, sediment sources were identified using samples obtained with automatic portable water samplers (Ottens and Rudd 1977). Many small tributaries and seepage channels were assessed for sediment transport.

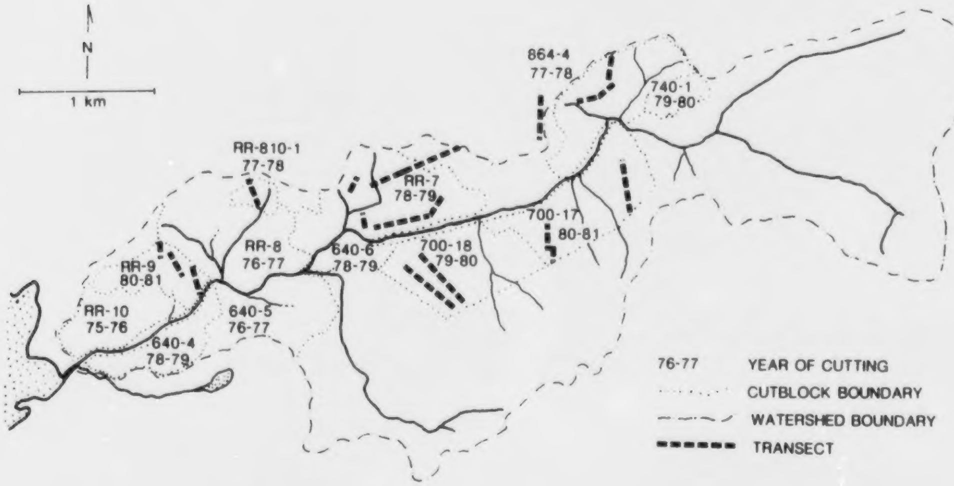

Figure 4. Carnation Creek drainage basin and locations of ground-surface survey transects within the cutblocks. Redrawn with permission from Smith and Wass (1982).

The transport of gravel and sand along the streambed (bedload movement) was assessed by direct measurement at B weir and by measuring deposition in pools at hydrological weirs, at the fish counting fence and in stream study sections (Fig. 1). Moving bedload was collected from a footbridge above B weir with a variety of Arnhem and basket samplers. Particle size distributions of the material were obtained by sieving these samples. Pools above the weirs and fence were periodically reexcavated during low flows and the material placed in the stream along the downstream banks. Annual changes of pools and of streambanks within the study sections was obtained from topographic maps. These maps were produced from surveys using a theodolite and stadia rods at 10 ft cross sections and along the center of the stream. Volumes of material trapped or scoured were calculated for all these sites. Thus, bed stability or rates of gravel movement were estimated.

Large organic debris was also located on these annual maps of the study sections (Fig. 1). Thus, stability indices, volumes, distributions, and movement rates could be estimated for debris in the channel. Changes of channel morphology and of fish rearing habitat were documented with these methods.

Changes of the streambed environment were measured by determining composition, dissolved oxygen, and permeability of the substrate. This environment is used by stream invertebrates and by incubating fish eggs. Frozen gravel cores were collected in study sections II to IX annually from 1973 to 1986 (Fig. 1; Scrivener and Brownlee, In press). Cores were also obtained three times (pre-spawning, post-spawning and before fry emerged) each year in section I, where most of the chum salmon spawned (Scrivener and Brownlee 1981). These cores were partitioned into layers and their particle size distributions determined by sieving. These data could be used to determine rates of deposition and scour of different particle sizes in the bed. Prior to gravel sampling, dissolved oxygen and water permeability in the streambed were measured using Winkler titration and Mark IV standpipe techniques (Scrivener and Brownlee 1981).

The inputs and transport of dissolved ions and stream nutrients were estimated when rain and stream water were analyzed for their chemical content. Rain water and stream water at B weir were collected twice a month between 1971 and 1986. Water samples were also collected monthly at C, E, H, and J weirs. Sets of samples were periodically obtained from tributaries 750, 1600, and 2600 (Fig. 1) and from the weirs during freshets. Alkalinity, pH, and electrical conductivity were determined in the field, while the remainder of the sample was frozen and transported to water quality laboratories for chemical analysis of 16 different ions (Scrivener 1975, 1982). This data was used to explain impacts on production of stream algae, to assess nutrient losses from forested land, and to assess impacts from a herbicide application.

Processes of Energy Gains and Losses in the Stream

Since the body temperatures of stream organisms and thus their metabolic rates are controlled by their environment, processes that influence stream temperature affect stream production. Therefore, solar radiation a major source of energy was recorded continuously at site A, and periodically in some study sections along the stream (Fig. 1). Air temperature was obtained at sites A, B, C, D, and E throughout the study. Water temperature was recorded continuously at B, C, E, H, and J weirs; and periodically at boundaries of the streamside treatments along the main channel (Fig. 2) and in tributaries 750, 1600, and 2600 (Fig. 1). Water temperatures were also obtained during 1981-82 from sites where sub-surface groundwater entered the stream (Hartman and Leahy 1983). These data recorded changes in the stream and they were used to develop empirical models that could explain changes that were observed among fish populations (Holtby and Newcombe 1982; Holtby 1988).

Dead leaves and needles that fell into the stream were major sources of energy for stream organisms. At Carnation Creek, >12 tons of this detritus material was processed annually by the stream (Neaves 1978). Most detritus was transported to the estuary, but some of it was incorporated in the streambed where it became the basis of production in the stream (Hynes 1970). During 1976 and 1977, detrital inputs were measured using catch trays and outputs transported by the stream were obtained at the counting fence (Neaves 1978). During 1984 and 1985, some of this work was continued in conjunction with the herbicide research at Carnation Creek.

Biological Processes in the Stream

Studies on periphyton biomass (attached algae) and species composition were carried out during 1974 to 1979. Stream algae consisted mostly of a layer of diatoms on rocks of the streambed (Shortreed and Stockner 1982). Accumulation rates of algae on submerged plexiglass plates were determined in study sections II, III, IV, V, VI, VIII, and IX, and at 4 sites in the estuary (Fig. 1). Two trough experiments were also carried out in which various mixtures of nutrients were added (Stockner and Shortreed 1978). During 1984 and 1985, this work was also continued when studies with herbicide application were occurring.

Stream invertebrates that feed on detritus and periphyton were also collected between 1971 and 1986. Most of these organisms were aquatic insects that lived in the streambed. They were collected and preserved each month from May to September and every two months from October to April within or nearby study sections III, IV, V, VI, VIII, and IX (Fig. 1). Later, the preserved insects were sorted, identified, counted, and measured with the aid of a microscope (Culp and Davies 1983). Their contribution to the diet of fish was explored in a series of seasonal feeding studies during 1971, 1973, 1977, and 1978. Their numbers were also monitored in valley-floor tributaries during the herbicide application. During 1980 and 1981, small instream experiments were done to assess the colonization and distribution responses of macroinvertebrates when various types of detritus or fine sediments were introduced to the streambed (Culp and Davies 1982).

Five series of fish population data were obtained annually from summer 1970 to spring 1986.

1. Counts, timing, sex ratios, size, and age were obtained from adult fish entering the stream and passing through the main counting fence (Fig. 1).

2. Numbers, size, timing, and age of fry and smolts leaving the stream through the counting fence were obtained during the spring,

3. Population estimates of juvenile fish were calculated three times a year in study sections II, III, IV, V, Vi, and VIII (May/June, July, September) and twice a year in section IX and tributary C (May/June, September) at Carnation Creek. These data were used to calculate survival and growth (Scrivener and Andersen 1984).

4. Population estimates of juvenile fish were also obtained in a section of 4 other Barkley Sound streams during August. These were external control sites.

5. Fish entering and leaving tributaries 750, 1600, and 2600 were enumerated between September 1 and May 31 (Fig. 1). Juvenile salmonids redistributed themselves into these valley-floor tributaries during freshets in the early autumn (Bustard and Narver 1975).

Other fish population data were obtained less frequently. During most springs, traps on the streambed collected chum salmon fry emerging below the counting fence. Thus, timing and sizes at emergence were obtained for estuary fry. Other studies in the estuary investigated the effects of salinity and gravel quality changes on incubating eggs of chum salmon, (Scrivener 1988), and differences between estuary and stream reared juvenile coho salmon (Tschaplinski 1982). During 1984, 1985, and 1986, baited minnow traps and mark-recapture techniques were used to determine growth and population changes in small tributaries and swamps during the winter (Brown 1985).

Results from the herbicide studies at Carnation Creek will not be reported here. A workshop is being planned for December 1987 at which these results will be discussed.

REFERENCES

Anon. 1973-1984. Sediment data from Canadian rivers. Inland Waters Directorate, Water Resources Branch, Water Survey of Canada, Ottawa, Ontario.

Brown, T. G. 1985. The role of abandoned stream channels as over-wintering habitat for juvenile salmonids. M.S. Thesis, Faculty of Graduate Studies, Department of Forestry, University of British Columbia, Vancouver, British Columbia. 134 p.

Bustard, D. R. and D. W. Narver. 1975. Aspects of the winter ecology of juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). J. Fish. Res. Board Can. 32: 667-680.

Culp, J. M. and R. W. Davies. 1982. Effect of substrate and detritus manipulation on macroinvertebrate density and biomass: implications for forest clearcutting, p. 210-218. In: G. F. Hartman [Ed.]. Proceedings of the Carnation Creek Workshop, a 10-year review. Pacific Biological Station, Nanaimo, British Columbia. 404 p.

Culp, J. M. and R. W. Davies. 1983. An assessment of the effects of streambank clear-cutting on macroinvertebrate communities in a managed watershed. Can. Tech. Rep. Fish. Aquat. Sci. 1208: 115 p.

Dryburgh, J. G. 1982. Carnation Creek logging and silvicultural treatment program, p. 36-44. In: G. F. Hartman [Ed.]. Proceedings of the Carnation Creek Workshop, a 10-year review. Pacific Biological Station, Nanaimo, British Columbia. 404 p.

Hartman, G. F. and R. M. Leahy. 1983. Some temperature characteristics of stream and intra-gravel water in Carnation Creek, British Columbia. Can. MS Rep. Fish. Aquat. Sci. 1731: 36 p.

Hartman, G. F., J. C. Scrivener, L. B. Holtby, and L. Powell. 1987. Some effects of different streamside treatments on physical conditions and fish population processes in Carnation Creek, a coastal rain-forest stream in British Columbia, p. 330-372. In: E. O. Salo and T.W. Cundy [Eds.]. Streamside Management: Forestry and fishery interactions. College of Forest Resources, AR-10, University of Washington, Seattle, WA. 98195. 471 p.

Hartman, G. F. and J. C. Scrivener. In prep. Forest harvest and processes of change within a coastal stream ecosystem, Carnation Creek, British Columbia. MS. Pacific Biological Station, Nanaimo, British Columbia. 286 p.

Hetherington, E. D. 1982. A first look at logging effects on the hydrologic regime of Carnation Creek experimental watershed, p. 45-63. In: G. F. Hartman [Ed.]. Proceedings of the Carnation Creek Workshop, a 10-year review. Pacific Biological Station, Nanaimo, British Columbia. 404 p.

Hynes, H. B. N. 1970. The ecology of running waters. University of Toronto Press, Toronto, Ontario. 555 p.

Holtby, L. B. 1988. Effects of logging on stream temperatures in Carnation Creek, British Columbia, and associated impacts on the coho salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 45 (3).

Holtby, L. B. and C. P. Newcombe. 1982. A preliminary analysis of logging-related temperature changes in Carnation Creek, British Columbia, p. 81-99. In: G. F. Hartman [Ed.]. Proceedings of the Carnation Creek Workshop, a 10-year review. Pacific Biological Station, Nanaimo, British Columbia. 404 p.

King, R. K. and E. T. Oswald. 1982. Revegetation of Carnation Creek watershed, p. 110-128. In: G. F. Hartman [Ed.]. Proceedings of the Carnation Creek Workshop, a 10-year review. Pacific Biological Station, Nanaimo, British Columbia. 404 p.

Krajina, V. J. 1969. Ecology of forest trees in British Columbia, p. 1-146. In: V. J. Krajina and R. Brooke [Eds.]. Ecology of Western North America. Vol. 2, No. 1 and 2. Department of Botany, University of British Columbia, Vancouver, British Columbia. 349 p.

Krygier, J. T. and J. D. Hall. 1971. Proceedings of a symposium Forest Land Uses and Stream Environment, Oct. 19-21, 1970. Oregon State University, Corvallis, OR. 252 p.

de Leeuw, A. D. 1982. The effects of logging on benthic invertebrate stream drift and trout growth rates in two small west coast Vancouver Island streams, p. 240-256. In: G. F. Hartman [Ed.]. Proceedings of the Carnation Creek Workshop, a 10-year review. Pacific Biological Station, Nanaimo, British Columbia. 404 p.

Narver, D. W. 1972. A survey of some possible effects of logging on two eastern Vancouver Island streams. Fish. Res. Board Can. Tech. Rep. 323: 55 p.

Narver, D. W. and B. C. Andersen. 1974. Fish populations of Carnation Creek and other Barkley Sound streams - 1970-1973: Data record and progress report. Fish. Res. Board Can. MS Rep. 1303: 115 p.

Neaves, P. I. 1978. Litter fall, export, decomposition, and retention in Carnation Creek, Vancouver Island. Fish. Mar. Serv. Tech. Rep. 809: 43 p.

Northcote, T. G. 1969. Symposium on salmon and trout in streams. Feb. 22-24, 1968. H. R. MacMillan lectures in fisheries. University of British Columbia, Vancouver, British Columbia. 388 p.

Ottens, J. and J. Rudd. 1977. Environmental protection costs in logging road design and construction to prevent increased sedimentation in the Carnation Creek watershed. Rep. BC-X-155. Can. For. Ser., Pacific Forest Research Center, Victoria, British Columbia. 28 p.

Oswald, E. T. 1973. Vegetation and soils of Carnation Creek watershed. Pac. For. Res. Cent., Can. For. Ser., Victoria, British Columbia, Int. Rep. 43: 38 p.

Oswald, E. T. 1982. Preharvest vegetation and soils of Carnation Creek watershed, p. 17-35. In: G. F. Hartman [Ed.]. Proceedings of the Carnation Creek Workshop, a 10-year review. Pacific Biological Station, Nanaimo, British Columbia. 404 p.

Peterson, N.P. and L.M. Reid. 1984. Wall-base channels: Their evolution, distribution, and use by juvenile coho salmon in the Clearwater River, Washington, p. 215-225. In: J.M. Walton and D.B. Houston [Eds.]. Proceeding of the Olympic Wild Fish Conference. Fisheries Technology Program, Peninsula College, Port Angeles, WA. 308 p.

Scrivener, J. C. 1975. Water, water chemistry and hydrochemical balance of dissolved ions in Carnation Creek watershed, Vancouver Island, July 1971 - May 1974. Can. Fish. Mar. Ser. Tech. Rep. 564: 141 p.

Scrivener, J. C. 1982. Logging impacts on the concentration patterns of dissolved ions in Carnation Creek, British Columbia, p. 64-80. In: G. F. Hartman [Ed.]. Proceedings of the Carnation Creek Workshop, a 10-year review. Pacific Biological Station, Nanaimo, British Columbia. 404 p.

Scrivener, J. C. 1988. Two devices to assess incubation survival and emergence of salmonid fry in an estuary streambed. N. Am. J. Fish. Manage. 8 (2)

Scrivener, J. C. and B. C. Andersen. 1984. Logging impacts and some mechanisms that determine the size of spring and summer populations of coho salmon fry (*Oncorhynchus kisutch*) in Carnation Creek, British Columbia. Can. J. Fish. Aquat. Sci. 41: 1097-1105.

Scrivener, J. C. and M. J. Brownlee. 1981. A preliminary analysis of Carnation Creek gravel quality data, 1973 - 1980, p. 197-226. In: Proceedings from the conference salmon-spawning gravel: A renewable resource in the Pacific northwest? Wat. Res. Cen., Washington State University, Pullman, WA. 285 p.

Scrivener, J. C. and M. J. Brownlee. In press. Effects of forest harvesting on spawning gravel quality and on incubation survival of chum (*Oncorhynchus keta*) and coho salmon (*O. kisutch*) in Carnation Creek, British Columbia. submitted to Can. J. Fish. Aquat. Sci.

Shortreed, K. S. and J. G. Stockner. 1982. The impact of logging on periphyton biomass and species composition in Carnation Creek: a coastal rain-forest stream on Vancouver Island, British Columbia, p. 197-209. In: G. F. Hartman [Ed.]. Proceedings of the Carnation Creek Watershed, a 10-year review. Pacific Biological Station, Nanaimo, British Columbia. 404 p.

Smith, R. B. and E. F. Wass. 1982. Changes in ground-surface characteristics and vegetative cover associated with logging and prescribed broadcast burning, p. 100-109. In: G. F. Hartman [Ed.]. Proceedings of the Carnation Creek Workshop, a 10-year review. Pacific Biological Station, Nanaimo, British Columbia. 404 p.

Stockner, J. G. and K. R. S. Shortreed. 1978. Enhancement of autotrophic production by nutrient addition in a coastal rain-forest stream on Vancouver Island, British Columbia. J. Fish. Res. Board Can. 35: 28-34.

Toews, D. A. and M. K. Moore. 1982. The effects of three streamside logging treatments on organic debris and channel morphology of Carnation Creek, p. 129-153. In: G. F. Hartman [Ed.]. Proceedings of the Carnation Creek Workshop, a 10-year review. Pacific Biological Station, Nanaimo, British Columbia. 404 p.

Tschaplinski, P. J. 1982. Aspects of the population biology of estuary-reared and stream-reared juvenile coho salmon in Carnation Creek: a summary of current research, p. 289-307. In: G. F. Hartman [Ed.]. Proceedings of the Carnation Creek Workshop, a 10-year review. Pacific Biological Station, Nanaimo, British Columbia. 404 p.

SESSION 1:
RUNOFF AND THE CHANNEL ENVIRONMENT

Moderator: D. Handley
MacMillan Bloedel Ltd.

HYDROLOGY AND LOGGING IN THE CARNATION CREEK WATERSHED - WHAT HAVE WE LEARNED?

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INTRODUCTION

Water is a crucial interface between forestry and fisheries. An overview of the watershed hydrology and logging impacts was given at the 1982 Carnation Creek Workshop (Hetherington 1982). This paper gives an update for some of the previous results and summarizes a variety of observations and insights pertaining to the hydrological regime of the Carnation Creek watershed.

CLIMATE AND STREAMFLOW

Because of the watershed's proximity to the ocean, rainfall dominates the precipitation. Significant rain-on-snow events seldom occur. Annual precipitation has varied from about 210 cm (station A) to over 500 cm (station L), averaging 20-30% greater at higher elevations than at lower elevations close to the ocean. Annual precipitation was relatively low during active logging and has been below average again since 1984 (Fig. 1).

The annual number of major runoff events or freshets is closely correlated with annual precipitation. For example, the number of storms with stream discharges capable of moving gravel in the mid-reaches of the flood plain (flows exceeding 6.7 cubic metres per second ($m^3 \cdot s^{-1}$) at B-weir) was also lower during active logging (Fig. 1). In contrast, the more extreme flow events are not tied to total precipitation. Annual peak flows have been highest since 1978 and particularly since the end of logging in 1981 (Fig. 1). The maximum recorded peak of 65 $m^3 \cdot s^{-1}$, which occurred in January 1984, was caused by heavy rainfall and has an estimated return period of once every 15-20 years. The second highest peak of 50 $m^3 \cdot s^{-1}$, which occurred in January 1982, resulted from a rain-on-snow storm.

SLOPE HYDROLOGY

An understanding of basic hydrological processes is an important first step to evaluating logging impacts on watershed hydrology.

Virtually all rainwater first soaks into the soil; surface runoff occurs only locally in saturated depressions or in barely definable ephemeral "channels." The soils remain moist year-round except on the surface after exposure following logging. Slope groundwater tables develop and rise rapidly after rain starts and fluctuate with variations in rainfall intensity. Groundwater has been recorded in every piezometer installed regardless of slope position. Maximum groundwater depths tend to decrease as slope gradient increases

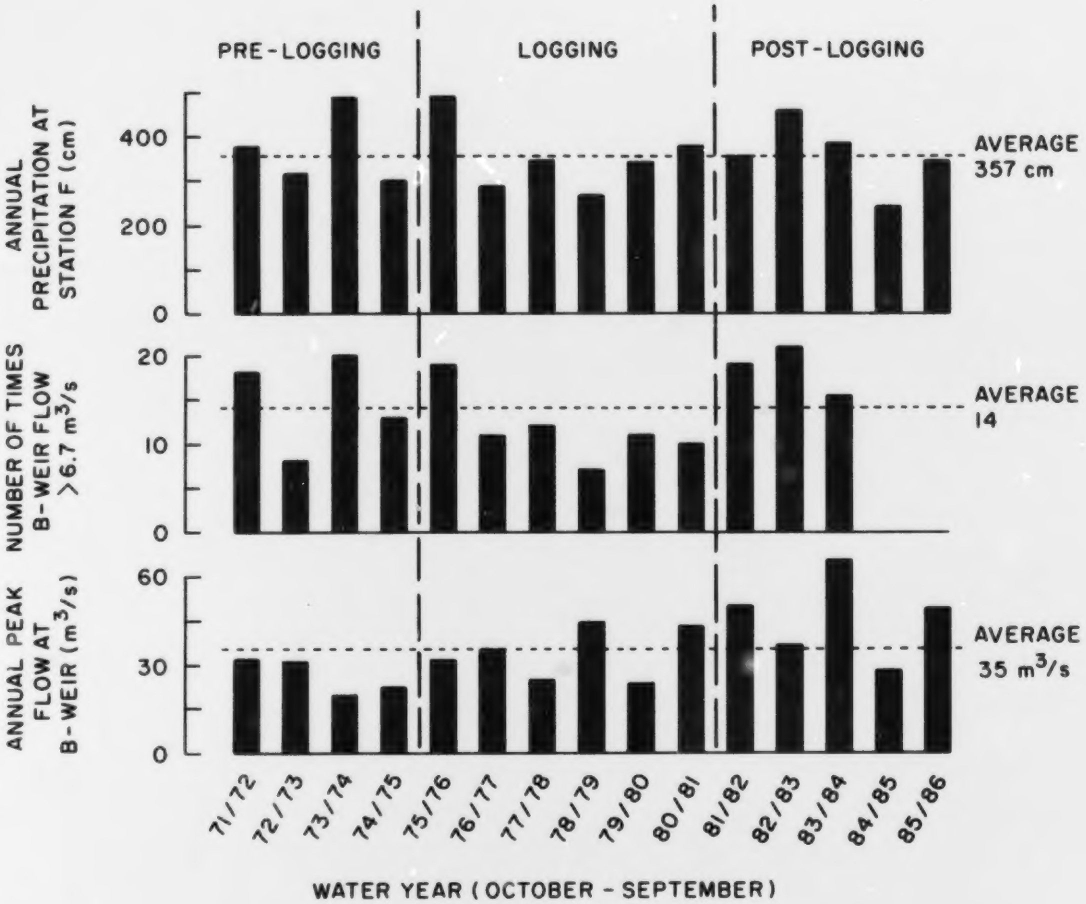

Figure 1. Annual trends in precipitation and streamflow in the Carnation Creek watershed.

and water tables are higher in the centre of small linear depressions than in adjacent terrain. Water flows rapidly in the soil through a complex network of preferred pathways which include interconnected decayed roots which act like pipes, layers or lenses of coarse materials, voids around rocks, along live roots, and worm holes. Rainwater moves down through the soil to the impermeable bedrock surface and then downslope along the bedrock with the flow tending to concentrate in depressions in the bedrock.

Road Impacts

Road construction has created surface runoff, by intercepting subsurface seepage and precipitation, and has thereby accelerated movement of water toward stream channels. This diversion of runoff by roads caused a landslide-triggering surcharge of water at one downslope location, reduced peak groundwater levels at another downslope location, created a new surface channel below a culvert, and changed the flow of water into a valley bottom side channel. No change was measured in downslope groundwater levels where road fill material was placed over the existing soil mantle.

Harvesting Impacts

Soil disturbance during yarding operations is the suspected cause of increased peak groundwater levels measured at a couple of sites. This disturbance of mineral soil caused local modifications in the pathways of water movement into and through the soil, but resulted in only very minor occurrences of localized surface runoff. Tree removal has changed the pattern and increased the amount of precipitation reaching the ground. These effects have caused no detectable change in slope groundwater levels. The soil moisture data have not yet been analyzed for changes in soil water contents.

EROSION, LANDSLIDES AND DEBRIS TORRENTS

Prior to logging, surface erosion in the watershed was negligible and there was little indication of mass soil instability in the areas to be logged. In the upper watershed above E-weir, however, there is evidence of natural soil instability, including several recent and old landslides and debris torrents which discharged material from very steep slopes directly into the stream channel. A landslide is a slumping of soil which moves downslope carrying trees or logging debris with it. A debris torrent is rapid movement of a mass of soil, gravel and woody material transported by water in a defined gully or channel.

Logging Impacts

The surface erosion observed since logging has been almost entirely road-related. During road construction, high sediment levels were recorded in small tributary flows just downslope from the roads (Ottens and Rudd 1975). However, much of this eroded material was deposited on the flood plain and did not reach the main channel. A few sections of road with steeper gradients have been eroded or the ditches widened, clearly illustrating the power of water to erode even coarse materials if allowed to gain speed and volume. Surface erosion was minimal on soils disturbed by yarding but did occur locally after prescribed burning.

Since logging began, there have also been two landslides and a debris torrent in clearcuts in January 1982, one landslide on a forested slope in 1983, plus four debris torrents and at least two small landslides in clearcuts and a major blowout of logs and debris from the lower canyon during the January 1984 storm. Most of the material from the slides and torrents did not reach the Carnation Creek channel, although one debris torrent may have contributed to the canyon blowout. Changes in groundwater regimes due to diversion of surface runoff by a road and by soil gouging during yarding were major causes of the two 1982 landslides, whereas windthrow was the probable triggering factor in the 1983 landslide. Logging debris in gullies and small soil slumps from gully sides contributed to the torrents.

VALLEY BOTTOM GROUNDWATER HYDROLOGY

Harvesting Impacts

Since harvesting of the valley bottom and adjacent slopes, summer groundwater levels in the alluvial flood plain in clearcuts RR-8 and 640-4 have remained higher through 1984 than before logging. A primary reason for the initial change was thought to be a reduction in water losses by evapotranspiration. The persistence of increased water levels in the face of vigorous vegetative regrowth suggests several possible causes: lower transpiration rates by the new vegetation than by the mature forest; increased subsurface seepage from side-slopes due to reduced evapotranspiration losses there; localized shifting of the stream channel and changes in height of the streambed. The effects on groundwater of scarifying for site preparation in the valley bottom in clearcut RR-8 are unclear.

STREAM HYDROLOGY

Streamflow in Carnation Creek is very responsive to variations in precipitation intensity, reflecting the responsiveness of slope groundwater tables and subsurface flow. The steep slopes, watertight bedrock, and shallow, porous soils offer little resistance to rapid downslope movement of water to the stream channel. During the winter, stormflows can equal the equivalent of up to 80-90% of storm rainfall because of limited available water storage capacity in the thin, moist soils. Streamflow is generated by subsurface flow to tributaries or the main channel and by direct precipitation onto surface channels. The tributary stream system expands during rain storms, providing increasing amounts of flow from the ephemeral side-slope surface channels. Stream discharge velocities are kept to a minimum by the low gradient of the main stream channel. During long dry spells in the summer, the major tributaries and the main stream always have some water flow, partly because of water stored in the alluvial flood plain.

Logging Impacts

Changes in streamflow after logging have occurred in a small 12-ha tributary (H watershed) in clearcut 864-4, but have not been detected in the main stream. In H watershed, annual runoff and summer low flows increased in the first two to three years after harvesting. The data indicate a return to prelogging values in subsequent years, but a leak in H-weir, discovered and repaired in August 1986, means that further flow measurements are needed to assess the validity of this finding. Peak flows also increased, primarily as a result of road construction. In the main stream at B-weir, peak flows showed no change after logging 40% of the watershed. The results for annual runoff and low flows are ambiguous, probably due to inaccuracies in low flow measurements and a possible small leak in the weir. The suggested role of fog-drip (Hetherington 1982) has been discounted.

On the basis of data analyses to date, logging impacts on streamflow generated by rainfall alone have been minimal in the main Carnation Creek. The observed changes in the stream channel have been mostly associated with major meteorological events, year-to-year changes in weather conditions, direct channel disturbance, and logging debris.

MANAGEMENT CONSIDERATIONS

The hydrological observations in the Carnation Creek watershed re-emphasize the need to pay careful attention to road and debris management. As a general axiom, the less the soil on steep slopes is disturbed the better, particularly by roads. Natural drainage patterns should be disrupted as little as possible. Water intercepted by roads should be dispersed with frequent cross drains and care should be taken not to divert water onto potentially unstable sections of slope. Preserving natural drainage patterns is the best way to minimize erosion, the risk of landslides and increased peak flows. Disruption of tributary flows to side channels in the valley bottom should be avoided where these can be identified. Severe soil disturbance by yarding on steep slopes should be minimized to avoid the changes in groundwater regimes that lead to slope instability. Keeping debris from major tributary gullies as well as the main stream will help minimize damaging debris torrents.

One of the main hydrological concerns with logging has been the possibility of increasing peak flows. For rain-only conditions roads have been shown to increase peaks in a very small drainage but not in the larger watershed up to at least a threshold of 40% clearcut with roads mostly on the contour. Water yield increases are an unavoidable consequence of clearcutting. They could be beneficial for fish habitat. However, such increases are likely to be short-lived on the west coast.

Harvesting alluvial flood plains will cause at least some increase in local groundwater tables. In the central portion of the Carnation Creek valley bottom, the observed changes in groundwater do not appear to have had any noticeable impact on streamflow, reforestation or fish habitat. In other areas, such changes could pose localized problems for reforestation but they could also improve the rearing habitat of side channels for fish.

APPLICABILITY TO OTHER WATERSHEDS

Most of the hydrological processes observed and documented in the Carnation Creek watershed are applicable to other west coast watersheds with steep slopes and shallow soils. The changes in slope, valley bottom and stream hydrology resulting from soil disturbance and tree removal should be similar. The accelerated occurrence of landslides and debris torrents in the Carnation Creek watershed, which is comparatively stable, will certainly occur elsewhere.

Some locations along the west coast of Vancouver Island that are more exposed to strong storm winds do receive greater amounts of annual precipitation and a higher frequency of major rains than the Carnation Creek watershed. Individual storms at Carnation Creek have probably rivaled those elsewhere in magnitude but not necessarily in number. The processes observed in the Carnation Creek watershed will still apply in such areas but the risk of logging-induced changes in watershed hydrology and slope stability may be higher. Rain-on-snow events will be more important in areas further removed from the ocean or with higher elevations. Peak flows from such events may be increased due to changes in snow accumulation and melt after harvesting. Streams without the buffer of a major flood plain will be more subject to sedimentation, while those with steeper channel gradients may experience higher and more damaging flow velocities.

COMPARISON WITH OTHER STUDIES

Despite different soils and climate, streamflow responses to clearcut logging for rain only conditions in coastal Oregon were similar to those found in [illegible] watershed: increased annual runoff and low flows and increased peak flows due to roads (Harr et al. 1979). Clearcutting alone had variable effects on average peak flows in Oregon due to differences in soil moisture, but little effect on larger peak flows once the soil became thoroughly wet (Harr 1976). In Carnation Creek and other coastal watersheds with moist soils, clearcutting alone should have minimal effects on peak flows caused by rain only. However, peak flows from rain-on-snow events have increased after harvesting in western Oregon (Harr 1986).

Hydrological responses and processes similar to those found in Carnation Creek have been observed and documented in the mountains north of Vancouver, including rapid groundwater response to storm rainfall, high soil permeabilities, the role of preferred pathways such as root channels, and stormflow generation (Cheng et al. 1975). These findings suggest that the information on processes from the Carnation Creek watershed has widespread applicability.

The important role of water in triggering small landslides has also been documented in coastal Alaska (Sidle and Swanston 1982).

CONCLUSION

The hydrology studies in the Carnation Creek watershed have confirmed much of what we already know or suspect from studies done elsewhere and have documented the nature and magnitude of processes locally. This information enables us to evaluate with more confidence the likely hydrological responses in other coastal watersheds. The data analyses are incomplete so there is yet more to be learned about Carnation Creek hydrology.

REFERENCES

Cheng, J.D., T.A. Black and R.P. Willington. 1975. The generation of stormflow from small forested watersheds in coast mountains of southwestern British Columbia. In Proc. Can. Hydrol. Symp. -75, Nat. Res. Coun. Can., Ottawa, pp. [illegible]2-553.

[illegible] 1976. Forest practices and streamflow in western Oregon. USDA For. Serv. Gen. Tech. [illegible]

[illegible] 1986. Effects of clearcutting on rain-on-snow runoff in western Oregon: a new look at old studies. Water Resour. Res. 22(7):1095-1100.

Harr, R.D., R.L. Fredriksen and J. Rothacher. 1979. Changes in streamflow following timber harvest in southwestern Oregon. USDA For. Serv. Res. Pap. [illegible] 22 p.

Hetherington, E.D. 1982. A first look at logging effects on the hydrologic regime of Carnation Creek Experimental Watershed. In Proc. Carnation Creek workshop, a 10-year review (G. Hartman, ed.), Pacific Biological Station, Nanaimo, B.C. pp. 45-62.

Ottens, J. and J. Rudd. 1975. Environmental costs in logging road design and construction. Can. For. Serv. Inf. Rep. BC-X-108, Victoria, B.C.

Sidle, R.C. and D.N. Swanston. 1982. Analysis of a small debris slide in coastal Alaska. Can. Geotech. J. 19(2):167-174.

STREAM CHANNEL MORPHOLOGY CHANGES SINCE LOGGING

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INTRODUCTION

Toews and Moore (1982) described the initial changes in stream morphology and organic debris which had occurred at Carnation Creek. Their results covered the pre-logging and logging phases of the watershed study, together with some of early effects of post-logging. The annual survey of the stream channel and debris within the 9 study areas has continued to the present time. In 1986 the survey data were finally computerized and analyses were started (Harris 1986). For this workshop, preliminary results will be discussed which show that the changes to the stream channel form and increased streambank erosion have continued since logging. Differences between the three treatment areas and within treatment areas are discussed. The same representative study areas III, VI and VIII are used to permit comparisons with the earlier paper.

As analyses are presently at a preliminary stage, results are not considered to be final and therefore suggestions for streamside management are tentative. The updated results are considered also in relation to the management implications presented in 1982 by Toews and Moore.

CHANNEL MORPHOLOGY

In the leave strip treatment, areas II & III, the channel has widened and deepened since logging. The annual rates of change have not altered from the pre-logging phase indicating that the system has continued to be dynamic and has remained stable (see Figures 1 to 3). Pool configurations have remained stable. Some infilling was noted recently in the upstream pool of the study area II, which may be caused by the presence of B weir where normal sediment transport is interrupted. Gravels are excavated from behind the weir to maintain the weir pool and then placed downstream where they can re-enter the sediment budget.

Study area IV has shown a lateral channel movement toward the right bank as the result of decreased debris stability following logging of the leave strip to remove blowdown. Also the pools have diminished due to introduction of upstream gravel. This is considered to be an important downstream effect of the intense logging treatment.

Table 1 presents the changes in channel width and depth for the three representative areas in both the pre- and post-logging phases of the study.

In the intense logging treatment (see Figures 4 to 6), area VI has shown widening of the stream channel and increased depth of the thalweg. Associated with this has been a straightening of thalweg and a change in pool configurations through the study area. In the pre-logging phase channel width increased, but at a much slower rate. In study area V the same trends are seen. In area VII, however, the channel has widened at a much increased rate since logging.

In the careful logging treatment (see Figures 7 to 10), the channel has widened at an increasing rate since logging as a direct result of the formation of a large debris jam. Channel depth decreased during

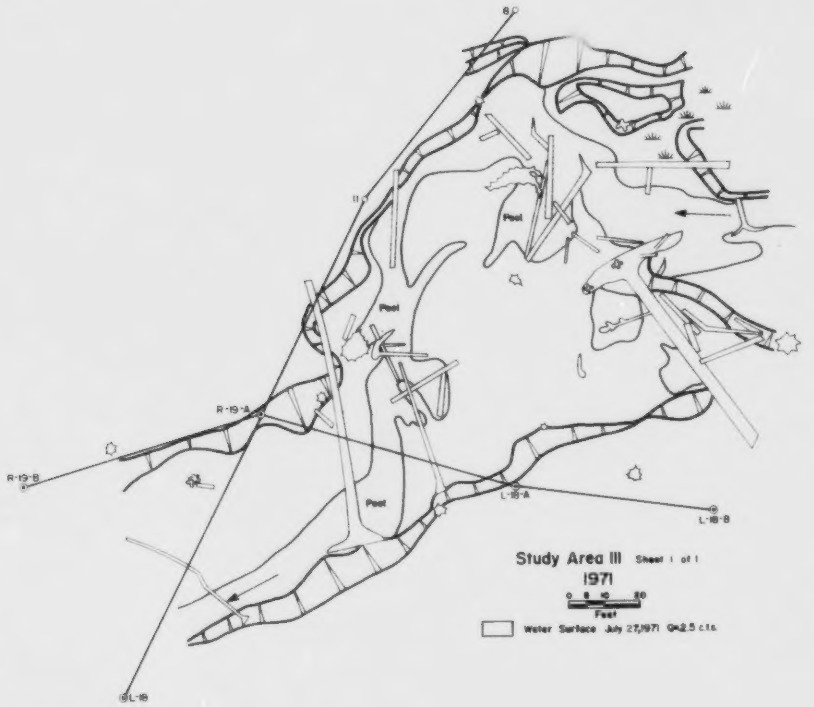
8
11
Pool
Pool
Pool
R-19-A
R-19-B
L-18-A
L-18-B
L-18
Study Area III Sheet 1 of 1
1971
0 5 10 20
Feet
Water Surface July 27,1971 Q=2.5 c.f.s.

Figure 1. Study Area III Map for 1971.

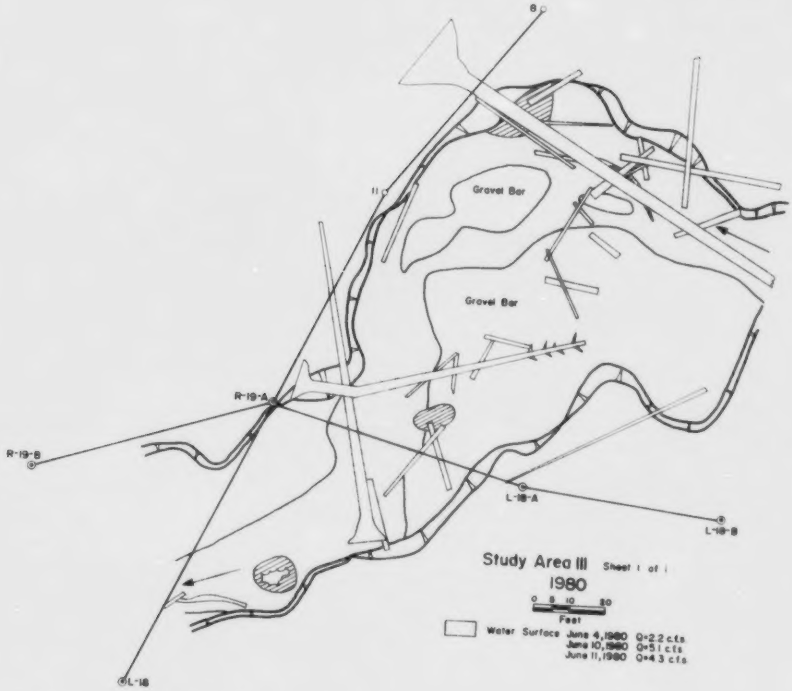
8
11
Gravel Bar
Gravel Bar
R-19-A
R-19-B
L-18-A
L-18-B
L-18
Study Area III Sheet 1 of 1
1980
0 5 10 20
Feet
Water Surface June 4,1980 Q=2.2 c.f.s.
June 10,1980 Q=5.1 c.f.s.
June 11,1980 Q=4.3 c.f.s.

Figure 2. Study Area III Map for 1980.

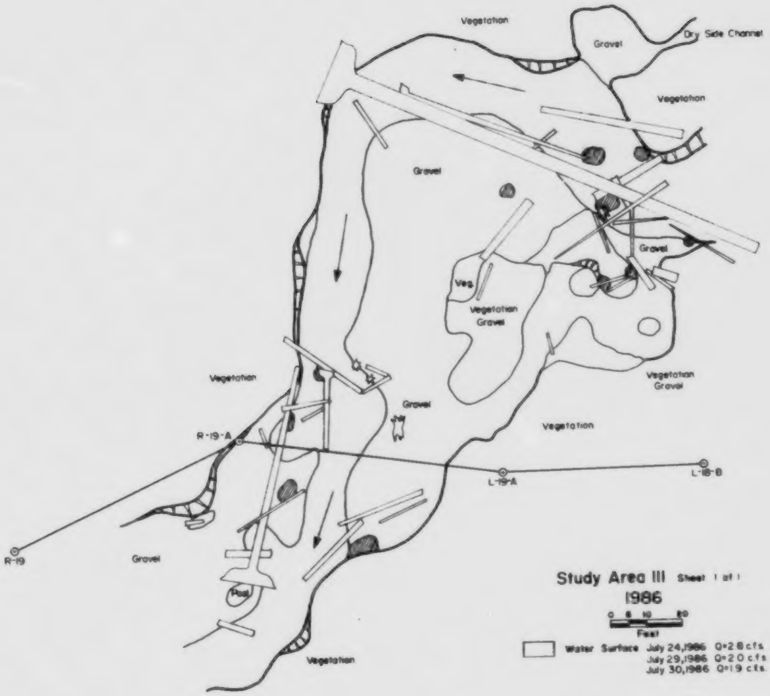

Figure 3. Study Area III Map for 1986.

Table 1. Changes in channel width and depth.

Study Area	Study Phase	Increase in Bank to Bank Width		Change in Thalweg Depth[1], m.
		Total, m.	Annual, m/yr.	
III	pre-logging	0.47	0.12	-0.13
	post-logging	0.65	0.11	-0.18
VI	pre-logging	0.38	0.10	0.17
	post-logging	1.53	0.22	-0.20
VIII	pre-logging	0.25	0.06	0.03
	post-logging	8.23	1.37	0.20

[1] - sign denotes increasing depth, + sign denotes decreasing depth.

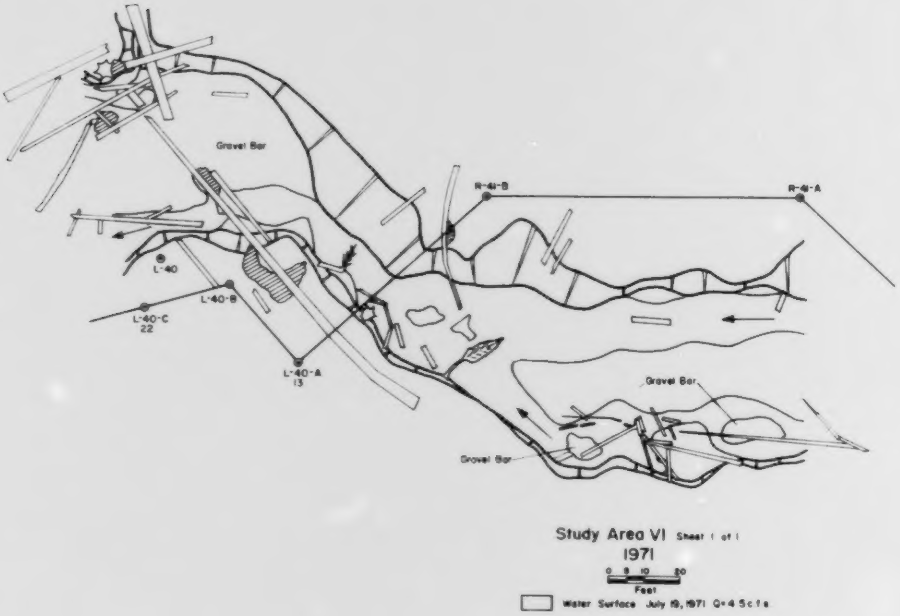

Figure 4. Study Area VI Map for 1971.

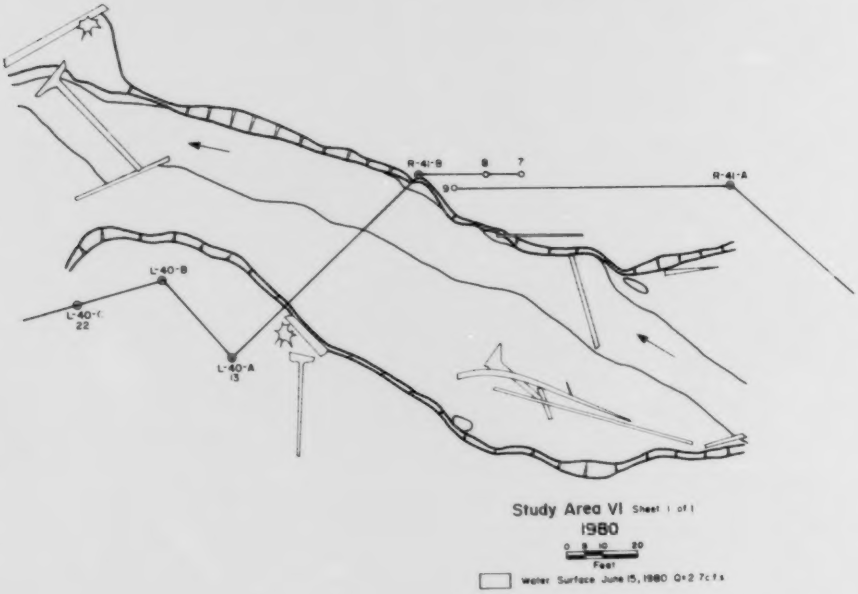
R-41-B
8
7
9
R-41-A
L-40-B
L-40-C
22
L-40-A
13
Study Area VI Sheet 1 of 1
1980
0 5 10 20
Feet
Water Surface June 15, 1980 Q=2.7 c.f.s.

Figure 5. Study Area VI Map for 1980.

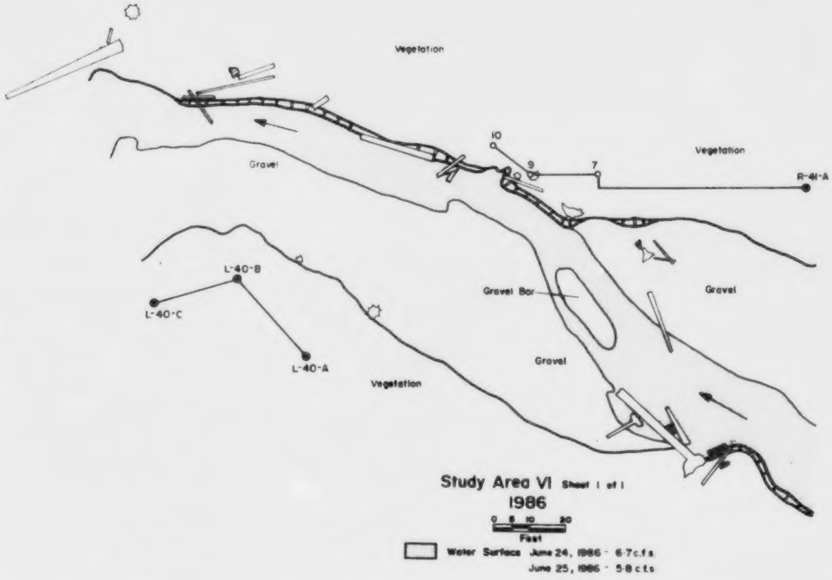

Figure 6. Study Area VI Map for 1986.

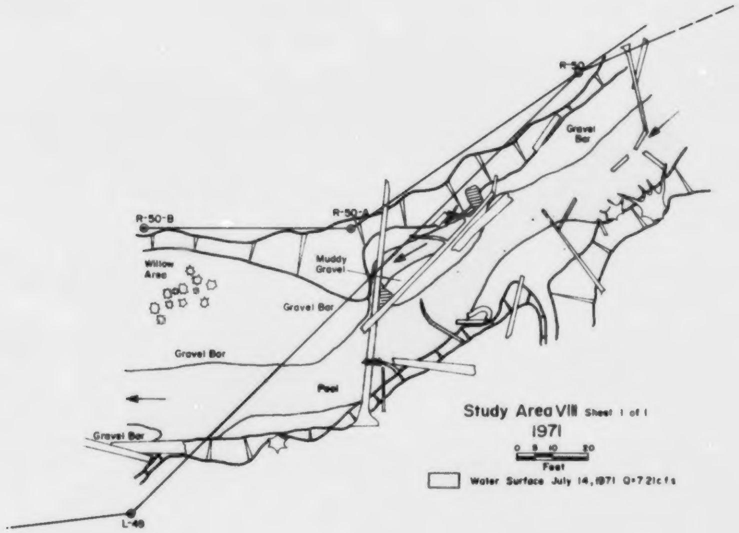

Figure 7. Study Area VIII Map for 1971.

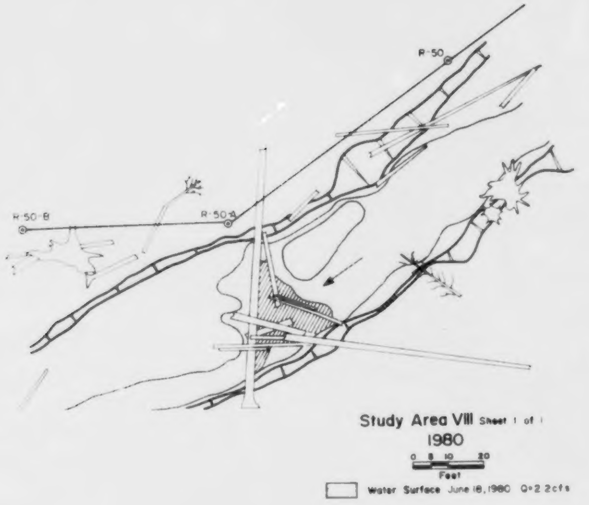
R-50
R-50-B
R-50-A
Study Area VIII Sheet 1 of 1
1980
0 5 10 20
Feet
Water Surface June 18, 1980 Q=2.2 cfs

Figure 8. Study Area VIII Map for 1980.

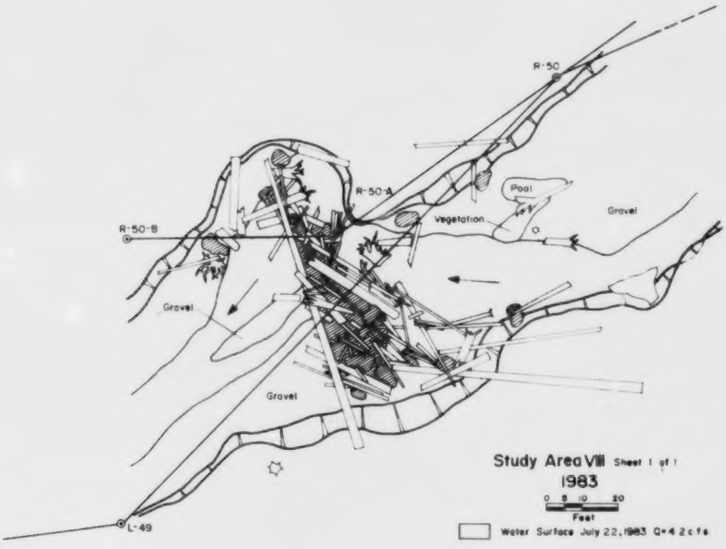

Figure 9. Study Area VIII Map for 1983.

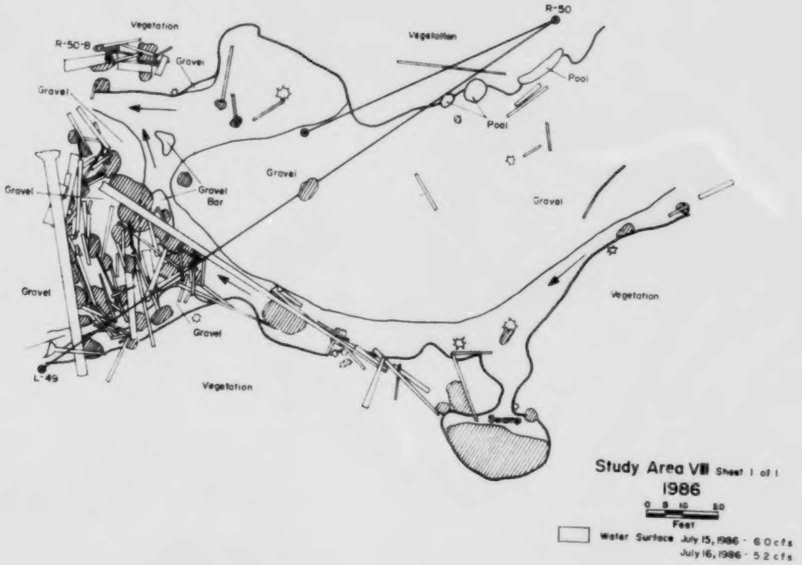

Figure 10. Study Area VIII Map for 1986.

this period primarily because of the gravel buildup behind the jam. The channel location has changed also in response to efforts by the stream to pass the obstruction. In the pre-logging phase channel depth and location remained stable.

Although the careful logging treatment included removal of all logging debris from the wetted perimeter, it is assumed that these materials were not placed far enough away from the stream bank to prevent their re-entry during subsequent peak flows. Since logging, there have been almost annual peak flows exceeding those measured in the pre-logging phase (Table 2). These peak flows have returned material to the channel causing the debris jam to enlarge and form a dam-like structure. In attempting to break this barrier, the stream has eroded its banks and enlarged the upstream cross-sections.

In January 1984, a major storm event produced the maximum peak flow of the whole study period, some 2291 cfs. During this storm there was a slide in the canyon above the treatment area which introduced debris into the stream channel. The resulting debris torrent travelled downstream some 400 to 500 metres toward the study reach, widening the channel and relocating LOD and sediment. Within study area VIII the log jam was moved downstream some 20 metres virtually intact. Very little new LOD was added to the jam, since most was stranded upstream on the banks and at several bends. The volume of gravel stored behind the jam at area VIII increased accordingly.

Channel sections which have increased width/depth ratios are characterized as unstable (Beschta 1986). This is because the bed shear stress would be increased and there would be high potential for bed load transport and bank erosion. In this study, reaches within the intense and careful treatment areas have shown these characteristics and are therefore described as unstable. In the leave strip treatment, the channel sections are characterized as stable, except for area IV which is experiencing downstream impacts from the intense treatment unstable channel.

STREAMBANK EROSION

In the leavestrip treatment, streambank erosion as measured by increased stream width (bank to bank) has increased in area II, remained constant in area III and has decreased in area IV. The decrease in area IV is attributed to the deposition of gravel on the left bank which has made identification of the bank position uncertain. Examination of the thalweg position shows a lateral movement towards the right bank where scouring continued to occur. It is assumed that these changes are the results of downstream effects from the intense treatment areas

Table 2. Peak flows from post-logging storm events.

Date	Peak Flow, cfs
Nov. 7, 1978	1563.2
Dec. 26, 1980	1521.0
Jan. 23, 1982	1766.0
Feb. 11, 1983	1279.4
Jan. 3, 1984	2291.3*)
	) same storm event
Jan 4, 1984	1925.0)

* record peak flow for study period 1971-1986.

immediately upstream of area IV.

In the intense treatment areas, streambank erosion has increased since logging in all three study sections. The most severe erosion has occurred in area VII, where scouring of the right bank has averaged a rate of 0.7 metres per year.

In the careful treatment area, streambank erosion has resulted in the bank to bank width increasing by 1.4 metres/year since logging. In this study reach, bank erosion occurred on both left and right banks. The primary cause of this erosion is attributed to the build up of the debris jam and resulting efforts of the streamflow to pass the obstruction. The maps of area VIII show that this increased level of erosion has continued each year. It is assumed that the present rate will continue until the stream has developed a new channel around the jam, or the jam weakens sufficiently for a storm event to breach it. At present the jam is building a large sediment wedge behind it, depriving downstream reaches of adequate gravel recruitment. Table 3 below summarizes the increases in bank to bank width since logging. Also it shows the streambank area which has been eroded in each study section. These latter figures are extrapolated for the length of stream channel within each treatment zone and indicate the extent of productive forest land that is lost (Table 4). Development of gravel bars occurs adjacent to some areas of eroding stream bank because channel form is changing. These bars are slowly being recolonized primarily by alder and they are not considered as additions of productive growing sites, able to offset the losses from erosion.

Estimates of the volume of material released into the stream channel through bank erosion have not been updated from 1982. The figures in Tables 3 and 4 illustrate the relative magnitude of the erosion volumes.

DISCUSSION

During the post-logging phase of the watershed study, there have been almost annual storm events which have generated higher streamflows than pre-logging storms did (Table 2). The peak flows generated by these storms have influenced the large organic debris arrangements and have resulted in the major channel changes that have been measured. The least changes have been observed in leave strip areas, which indicate the importance of maintaining the natural LOD, preserving the streamside vegetation, leaving streambanks undisturbed and providing a future source of LOD.

Results from the intense treatment areas are not so surprising, in that channel changes would be anticipated from alteration of debris and logging to streambanks where no precautionary measures were taken.

The careful treatment results show that events occurred which were not anticipated. Small debris from logging was cleaned out from the stream channel, but quantities of this material subsequently re-entered the channel and created the log jam in study area VIII. It is assumed that during the debris

Table 3. Streambank erosion after logging.

Study Section	Bank to Bank Width Change, m.	Length of Section, m.	Area Lost m^2	No. of Years Since Logging
II	.84	82	69	7
III	.65	79	51	6
IV	.45	63	28	7
V	2.00	70	140	7
VI	1.53	62	95	7
VII	4.83	58	280	7
VIII	8.23	52	428	5

Table 4. Estimates of rate of streambank erosion by logging treatment.

Logging Treatment	Length of Channel Affected, m.	Streambank Area Lost, m^2	Calculated Annual Rate of Loss m^2/km/yr
Leave strip	950	618	93
Intense	950	2650	399
Careful	650	5350	1646

clean up, material was not placed far enough back from the bank to prevent its re-entry during the subsequent peak flows. The falling of girdled alder trees along the bank has added to the demise of the living root network protecting the streambanks. The occurrence of a debris torrent in the canyon with its downstream effects through the careful treatment area has compounded the impacts with the addition of more unstable debris stranded on the banks and the introduction of a large volume of sediment. Undoubtedly this stranded debris will continue to re-enter the stream channel during future peak flows, and will continue to influence the stream channel.

The results show that the changes in channel morphology which Toews and Moore described in 1982 have continued through the post-logging phase. There is evidence that the changes in channel form and streambank erosion have increased in both the intense and careful treatment areas. Also there is evidence of downstream effects from these areas. The management implications which Toews and Moore (1982) cited with respect to streamside logging are still valid. The effects of the logging treatments on both large and small organic debris are presented by Harris (these proceedings).

The impact of the changes in stream channel and streambank erosion on changes in gravel quality are presented by Scrivener and Brownlee (these proceedings).

MANAGEMENT IMPLICATIONS

The importance of LOD to stream channel form and stability is clearly demonstrated. The maintenance of large stable debris in the channel is required to permit the channel to remain stable during peak flows from storm events. The system at Carnation Creek has experienced higher peak flows in the post-logging phase than in pre-logging calibration and during the logging phase.

It has been demonstrated that the intense treatment of logging is not appropriate even for small stream systems such as Carnation Creek. The careful treatment has also not proved as effective as previously thought. The higher peak flows since logging have reintroduced small unstable debris from logging back into the channel, where it has caused severe channel changes and increased streambank erosion.

The use of leave strips to protect the channel form is demonstrated by the results from study sections II, III and IV. The width and composition of the leave strips require further study to determine the most effective and economic configurations. Some loss of mature timber must be incurred in order to provide future sources of LOD to replenish present conditions as they evolve. Some disruption of streambanks will occur as material blows down, but this will encourage the natural dynamics of the system.

The results in the intense treatment indicate clearly that cross-stream falling and yarding should be avoided. The resulting disturbance to streambanks and introduction of small unstable debris increase streambank erosion and changes in channel form.

Careful treatments involving removal of all logging induced debris from the wetted perimeter are not always effective. Material may not be placed far enough away to ensure that re-entry during storm generated peak flows does not occur.

A living root network is required to provide stability for streambanks. This includes the component provided by mature trees. This living root network plays a similar role in streambank stability as it does for stability on steep hill slopes.

REFERENCES

Beschta, R. L. and W. S. Platts, 1986. Morphological features of small streams: significance and function. Water Resources Bulletin, Vol. 22(3): 369-379.

Dryburgh, J. G., 1982. Carnation Creek logging and silvicultural treatment program. In: Proceedings of the Carnation Creek Workshop: a 10 year review. G. Hartman, [Ed.]. Pacific Biological Station, Nanaimo, B.C.

Harris, C. D., 1986. An investigation of the effects of logging on instream debris and stream channel morphology in Carnation Creek. Report on file at Dept. of Fisheries & Oceans, Vancouver.

Toews, D. A. A. and Moore, M. K., 1982. The effects of three streamside logging treatments on organic debris and channel morphology of Carnation Creek. In: Proceedings of the Carnation Creek Workshop: a 10 year Review, G. Hartman, (Ed.) Pacific Biological Station, Nanaimo, B.C.

A SUMMARY OF THE EFFECTS OF STREAMSIDE LOGGING TREATMENTS ON ORGANIC DEBRIS IN CARNATION CREEK

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Debris dynamics have been studied for sixteen years in the Carnation Creek watershed. Four reports (Schultz 1981, Toews & Moore 1982a, 1982b & Harris 1986) have documented the changes in debris piece size, stability, and volumes throughout the study period. The results of these studies clearly identify the importance of large organic debris in small coastal streams.

Large woody debris (LWD) is important in providing valuable rearing and overwintering fish habitat in the form of cover, food for aquatic insects, habitat diversity by pool and riffle formation, and sediment and energy dissipation (Hartman and Tschaplinski (1973), Swanson et. al (1984), House and Boehne (1985), Harris (1984). A new concept in debris dynamics, the index of debris complexity, has been developed as an aid to field staff and resource managers to determine habitats of low and high debris complexity.

Debris complexity is the amount, structure, variety, and placement of materials that compose its mass. Several factors make up the debris complexity index. These are debris factors (surface area, volume, surface area to volume ratio and stability) and stream factors (depth, debris stream position, and velocity). An index of debris complexity is developed by ranking each of these factors on a scale of 1 to 10. The addition of all the factor rankings determines the index of debris complexity. Higher debris complexity is positively correlated with fish production (see Figure 1).

BACKGROUND:

Several studies have observed the debris dynamics in Carnation Creek. In 1981, Schultz International summarized debris volumes, pieces numbers and stability for each treatment type for several study years in the watershed. Toews and Moore (1982a) observed the impact of one intense logging treatment on the stability and distribution of large organic debris, and this report was updated to evaluate the impacts of the three streamside logging treatments on Carnation Creek (Toews and Moore 1982b) . In 1986, AquaFor Consulting Ltd. standardized and analysed all existing debris and channel information to date to determine the effects of three logging treatment types on the watershed (Harris Report 1986). Preliminary results from this update are presented here, together with some suggested management implications.

METHODS

Debris data were collected each year using standard surveying techniques. Data from all years were standardized and entered into a computer. Analyses to determine the effects of streamside logging on several debris parameters included: mean and total values of surface area, volume, and number of logs per 30 meters of reach. Data were summarized annually for each study area, treatment type as well as for the entire watershed. For this workshop analyses centered on the years following the 1982 Toews and Moore reports in order to update the information.

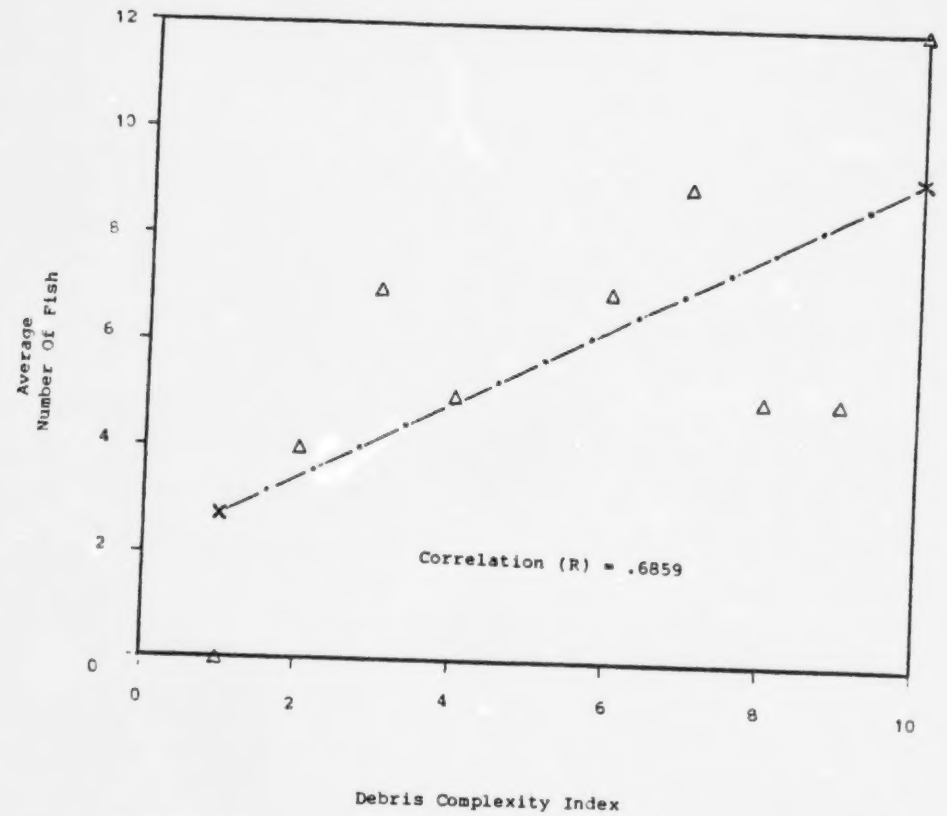

Figure 1. Relationship between number of fish and debris complexity index. (Harris 1984).

TOEWS AND MOORE REPORT (1982) REVIEW

1. There was a significant reduction in stability (post logging) in the careful and intense treatment. The leave strip treatment showed an increase in the mean stability index after logging.
2. The change in the number of pieces was generally a large increase immediately following logging (due to the introduction of tops, branches, broken pieces, etc.) which quickly flushed through the reaches and a return to prelogging levels.
3. The intense treatment showed a large increase in small organic debris (SOD) piles. These piles were very mobile.
4. Changes in debris dynamics were noticed immediately, whereas changes in channel features took time because they were related to storm events, sediment movement and bank erosion in addition to the influences of large organic debris.
5. The careful and intense treatments had similar results of reduced stability of LOD and introduction of SOD piles, which contributed to changes in channel form and streambank erosion. In these treatments, debris was smaller in size and volume.

1986 HARRIS REPORT RESULTS:

1. Since 1982, the leave strip treatment showed a very slight increase in number of pieces, surface areas and volumes of debris. The most notable changes occurred in study area three where there was a large increase in the amount of small debris immediately following logging. This debris was eventually flushed from the reach. Several large pieces then blew down, resulting in a replenishment of the volumes lost by smaller

debris and then a gradual increase in all debris parameters was observed.

2. Significantly increased surface areas, volumes and number of pieces were observed in the careful treatment area from 1980 to the present. This is the result of the large debris jam which started to accumulate at the time of logging. However, in the winter of 1983/84 a record storm event triggered a debris torrent (from the canyon above) depositing a large amount of debris and sediment in the treatment area. The changes in debris structure, channel form, and channel functioning were catastrophic.

3. In the intense treatment, the number of logs increased in all reaches studied during the post logging period. However, surface areas and volumes decreased immediately following logging indicating a large input of many small pieces of debris. From 1982 to the present, there has been an increase in all debris parameters measured, suggesting that the debris in the creek is not as small nor is it breaking up as was seen immediately after logging.

4. The bufferstrip treatment (study Area 9) showed a substantial increase in all debris parameters measured following logging due to the high incidence of blowdown. The increase in surface area and volume parameters has continued, yet the number of logs entering the channel seems to have ceased in 1983, thus marking the end of the majority of blowdown for the area. Analysis of stream morphology parameters indicates that the reach has not changed dramatically due to the adjacent logging treatment. Streambanks in this reach have remained stable.

5. Analysis of debris dynamics on a watershed basis provides a generalized viewpoint of the effects of logging on several stream reaches. The total values of all debris parameters have fluctuated over the entire study period, whereas mean values for surface area and volume fluctuated minimally with peaks in 1973 and 1981. In the post logging period, all debris parameters showed increases to 1982 and then appear to have reached a point of equilibrium. This suggests that the debris dynamics in the watershed may be stabilizing.

DISCUSSION

The sixteen year study on debris dynamics in Carnation Creek has displayed the importance of large woody debris in determining channel stability and structure to mitigate changes. In all reaches studied, loss or movement of debris resulted in changes in bank stability, gravel bars, and pool complexes. These were magnified in the intense logging treatment, whereas the buffer strip and leavestrip treatments showed changes on a smaller scale. Removal of large woody debris from the stream can result in reduction of important debris structures for channel stability. The careful treatment was designed to identify the effects of stream cleaning, however the treatment results were masked by impacts of record storm events. The intense treatment resulted in reduced mean debris volumes and large increases in piece number in the study reaches. Bilby (1984) indicates immediate effects of debris alteration or removal on channel stability could be reduced by minimizing changes to pieces that determine channel morphology.

Toews and Moore (1982b) suggested that in the intense and careful treatments, a possible long term change in debris following logging is the erosion of debris jams and the gradual breakdown and removal of small debris piles. Also, existing channel debris will gradually decay and new material (which is smaller) would be added towards the end of successive rotations. Harris (1986) indicates that the number of debris jams have increased, especially in the careful logging treatment. In addition, after logging, there is an increase in the mean number of pieces in both the leave strip and intense treatments (Table 1) coupled with an overall decrease in mean volumes in five of the seven study reaches (Table 2). This suggests that either the larger pieces are being broken down or that a large amount of small debris from logging entered the stream channel, resulting in an overall decrease in mean piece volume. Bilby (1984) showed that the propensity of a piece to move is closely related to its length. Longer pieces usually stabilize at several points along their length. In Carnation Creek, all study areas (except 2, 3 and 9) showed decreasing mean length values. Bilby also reports that diameter of debris influences the probability of the piece moving.

Debris size is a major component of the debris complexity index. Complexity is indicated by review

Table 1. Mean number of pieces in each study area before and after logging.

Study Area	Before Logging	After Logging	Treatment
II	34.0	36.6	Leave Strip
III	27.3	41.4	Leave Strip
IV	32.0	48.7	Leave Strip
V	14.2	49.3	Intense
VI	25.0	22.6	Intense
VII	25.3	29.3	Intense
VIII	19.8	63.6	Careful

Table 2. Mean volume in each study area in the period before and after logging.

Study Area	Before Logging	After Logging	Treatment
II	29.6	22.4	Leave Strip
III	34.2	44.2	Leave Strip
IV	37.4	35.3	Leave Strip
V	25.4	24.7	Intense
VI	26.0	15.0	Intense
VII	78.2	15.7	Intense
VIII	14.3	29.5	Careful

of several debris parameters (surface area, volume, the ratio of surface area to volume, piece number, etc.). The standard deviations of these parameters are further indicators of debris complexity. Thus, high standard deviations indicate higher debris complexity because of the wider range of variation. High standard deviations of mean volumes and surface areas were noted in the leave strip treatment. The higher the debris complexity index, the more important the role of the debris to channel stability and structure and fish habitat.

MANAGEMENT IMPLICATIONS

1. Stream reaches with more debris (especially debris with high complexity) have the ability to moderate the effects of changing channel hydraulics as well as the impacts of various logging treatments adjacent to an area.

2. Debris position, size and orientation can indicate future changes in debris and channel morphology features.

3. Enhancement structures, such as gabions and LWD placement should imitate the effects of large organic debris in channels. Also, they may be useful for enhancing debris complexity. Any placement of artificial structures should be adapted to enhance hydraulic features of the channel.

4. The type of debris which is desirable for placement is wood with high complexity (e.g. large rootwads) and a mixture of coniferous and hardwood species.

5. Management in some streamside vegetation zones should include leaving large trees which will eventually fall into the stream. A continuous debris source over successive rotations is critical to maintenance of productive fish habitat.

6. The immediate effects of debris alteration or removal on channel stability could be reduced by minimizing changes to pieces that determine channel form.

7. If blowdown occurs, it may benefit fisheries and the biological integrity of streams. Local bank-cutting will occur, but habitat diversity can increase. Channel and sediment systems adjust to debris presence. Debris removal on the other hand may prolong the period of instability.

8. Swanson et al. suggest streamside management strategies:
    1) coppicing hardwoods - to provide windfirm shade in the next rotation.
    2) establishment of hardwoods along streams late in a rotation.
    3) thinning around or topping streamside conifers of low commercial value.

9. The debris complexity index is a useful field tool to identify areas of fish habitat.

10. Further research is required to address the quality and quantity of woody debris that is required within the stream and riparian zones to maintain or enhance the aquatic ecosystem.

REFERENCES

Bilby, R.E. 1984. Removal of woody debris may affect stream channel stability. Journal of Forestry, Vol. 82, No. 10. Oct. 1984.

Harris, C.D. 1984. Organic debris complexity and its effect on small scale distribution and abundance of coho (*Oncorhynchus kisutch*) fry populations in Carnation Creek, B.C. BSF Thesis.

Harris, C.D. 1986. An investigation of the effects of logging on instream debris and stream channel morphology in Carnation Creek, British Columbia. Report on file at Dept. Fisheries and Oceans, 555 W. Hastings St., Vancouver, B.C.

Hartman, G.F. and P.J. Tschaplinski. 1983. Winter distribution of juvenile salmon (*Oncorhynchus kisutch*) before and after logging in Carnation Creek, British Columbia and some implications for overwinter survival. Can. Jour. Fish. and Aq. Sciences. 40:452-461.

House, R.A., and P.L. Boehne. 1985. Evaluation of Instream Enhancement Structures for Salmonid Spawning and Rearing in a Coastal Oregon Stream. North American Journal of Fisheries Management 5:283-295, 1985.

Schultz International, Ltd. 1981. An analysis and summary of data on changes in debris and channel morphology in Carnation Creek. 1971-1980. Report on file at Pacific Biological Station, Nanaimo, B.C. 26 pp.

Swanson, F.J., Bryant, M.D., Lienkaemper, G.W. 1984. Organic debris in Small Streams, Prince of Wales Island, Southeast Alaska. USDA PNW-166.

Toews, D.A.A., and M.K. Moore. 1982a. The effects of streamside logging on large organic debris in Carnation Creek, British Columbia. Ministry of Forests, Land Management Report II, Vancouver, B.C.

Toews, D.A.A., and M.K. Moore. 1982b. The effects of three streamside logging treatments on organic debris and channel morphology of Carnation Creek. In: Proceedings of the Carnation Creek Workshop, A 10 year review. G. Hartman [Ed.]. Pacific Biological Station, Nanaimo, B.C.

PANEL DISCUSSION
SESSION 1: RUNOFF AND THE CHANNEL ENVIRONMENT

RESPONSE BY BOB WILLINGTON,
BCFP RESOURCE PLANNING GROUP

The following summarizes some of my reactions and thoughts to the information presented by Eugene, Les and Cathy.

It is certainly appreciated that the Carnation Creek channel has undergone morphological change and that some of this change is related to logging. As is frequently the case at the field operating level, morphological change to channels is one of the qualitative indicators that landuse is potentially affecting the channel environment and that further inquiry as to the cause(s) of this change is warranted.

Hydrologic rate-of-cut has been, and still is, a concern to both agencies and industry on the coast and it is reassuring that Eugene Hetherington reports that the removal of timber from 40% of the watershed and the associated roads have not increased rain-only peaks flows as measured at B weir. He does, however, report that roads had an effect on peak flows in a small watershed (H weir) and that road drainage contributed to slope failures. It is encouraging that roads, rather than the rate of timber removal, have contributed to slope stability and peak flow changes because the road effects are visible and therefore amenable to management and subsequent mitigating effects. It is noteworthy that although he suggests the same peak flow effects may not hold for rain-on-snow events, only one such event is available for analysis.

Les Powell notes the occurence of several recent storm events that resulted in higher peak flows than occurred in the pre-logging and logging phases. I am left to wonder if these episodic events may have induced changes in channel morphology irrespective of land use effects. A further concern I have on the channel morphology results he reports is the effects of upstream processes on downstream processes. The main-stem debris torrent most likely confounded the "careful" logging treatment and the intensive treatment (reported by Toews and Moore, 1982, as being more extreme than normally allowed!) most likely confounded the buffer strip treatment. Thus, streamside treatment effects cannot be treated as being mutually exclusive!

Cathy Harris reported on the merits of high organic debris complexity to the maintenance of channel morphology stability and some of the consequences of LOD changes. One question I have, since we have to deal with it at the field level for a wide variety of stream-debris combinations, is that of how we judge the degree by which the organic debris is stable and beneficial or unstable and deleterious?

It will be interesting to learn in Session 5 how the reported changes in stream morphology have affected the fishery resource. Given that some of the effects reported in our Session may be less than acceptable to the fish, it is encouraging that many of these effects relate to the quality of road construction and harvesting, rather than the quantity. As such, these potentially deleterious effects can likely be mitigated through the application of appropriate road construction and harvesting techniques. It is also noteworthy that a natural event may have caused channel changes that surpass those induced by road construction and harvesting.

RESPONSE BY DAVID A.A. TOEWS,
MINISTRY OF FORESTS AND LANDS

In my brief opportunity to comment on these papers I will initially make a personal comment, secondly I will comment on the contribution of the Carnation Creek results to several ongoing debates within the hydrological community, and thirdly will comment on the applicability of the results to other areas of B.C.

I had the opportunity to participate in the Carnation Creek project for six years between 1975 and 1981. This was the harvesting phase of the Carnation Creek project. Because this was a long-term project where the objective was to not only measure impacts, but to understand processes behind those impacts it provided an excellent complimentary background to the consulting work I was involved in.

In consulting work one is often called on to make judgement calls, projecting risk and possible impacts. A long-term project such as this provides an invaluable testing area to ground truth such judgement calls.

There are two general topics of ongoing debate between hydrologists and land managers that urgently need more information. These topics are "harvest scheduling" and "cumulative impacts".

With respect to these two related topics, I believe that a lot ot useful information is emerging from the Carnation Creek study to address these issues. I would however, caution participants in this workshop not to interpret the results too simplistically.

With respect to the topic of "harvest scheduling", a hydrologist is often asked "How much of this watershed can I harvest and what is the optimal spatial pattern of harvest?" At the simplest level one could state that 41% of the Carnation Creek watershed has been logged and fish production is continuing more or less undiminished. I think that on considering the time and resources our agencies have sunk into the project, we owe it to ourselves to examine the results more closely. The channel has changed in a fairly dramatic manner after logging and is continuing to change. These changes are mainly traceable to streamside treatments even though peak flows have generally been higher during and following logging than during the calibration period.

The interesting point, however, is that the streamside impacts are distributed throughout the stream channel rather than being strictly confined to the area of the extreme streamside treatment. The biophysical changes to the channel are affecting salmonid production in complex ways. The best description of the kind of changes occurring was in the 1982 workshop proceedings and I hope we get further clarification in these proceedings.

With respect to the topic of "cumulative impacts" the Carnation Creek information is valuable because the 15-year time period is approaching that which is necessary to follow biophysical changes through to biological changes. The information presented today shows that the time after logging can be more important than during logging in terms of impacts to stream channels.

With respect to applicability to other areas in B.C., I think it is worthwhile to look at those parts of the work presented that are widely applicable versus those results where the applicability is geographically limited. Certainly a coastal system such as Carnation Creek has a different hydrologic regime than the interior of B.C., where we are dealing with snow dominated systems. Results from the Carnation Creek project with respect to peakflow changes, water yield changes, and groundwater changes are particularly applicable to coastal ecosystems. When we start looking at channel systems, however, the results become widely applicable. The results that Cathy and Les presented are widely applicable throughout B.C.

Interactions between streamside vegetation, channel debris, and channel form are very similar wherever one goes in B.C. Carnation Creek and other coastal streams differ in that the driving forces bringing about changes in the channel are more dramatic that one would find elsewhere in B.C. If one examines stream channels elsewhere one sees similar changes taking place, however, usually not in such a dramatic fashion.

RESPONSE BY B. CERENZIA, MINISTRY OF ENVIRONMENT AND PARKS

I found the presentations to be both informative and interesting. The results of the findings support numerous areas of concern that I, as a field person, must face on a constant basis.

I would like to briefly address the three papers with comments on how some of the findings will affect me as a field person and to present some problems that I feel require further study.

A. Hydrology and logging on the Carnation Creek watershed what have we learned? (E. Hetherington)

In his discussion on slope hydrology and erosion, Eugene states that roads accelerate both surface erosion and the movement of water towards stream channels.

- This emphasizes the potential for problems if roads are not located, constructed, and maintained with minimizing surface runoff in mind.

- Lack of road maintenance is a chronic problem that one faces in the field. Although road maintenance is beneficial to the companies, it is often the first to suffer as the result of other priorities, and it often becomes non-existent once an area is completely finished and off the books.

- The entire problem surrounding unused roads can be greatly alleviated if a good program of road retirement is ongoing.
- It is indicated that two landslides in the Carnation Creek area were identified as having been the result of changes in ground water regimes due to road diversion of surface runoff and soil gouging.
- This, occurring in areas that gave little indication of mass soil instability prior to logging, is somewhat disconcerting.
- We have experts that can aid us in problem areas, but what are we supposed to do when these slides start occurring in stable areas? Road construction and maintenance appears to be the answer.
- It is suggested that logging debris in gullies and small soil slumps from the gully sides contributed to the torrents.
- This gives creedence for a need to design landings to avoid the gouging of gully sidewalls and dictates minimizing the amount of logging debris that is to be left in gullies.
- A point in question here is, does the fact that logging debris in gullies that could contribute to a debris torrent direct one to remove debris from the gullies regardless of the stream's potential to transport debris?
- Currently, the opposition to removing logging debris from those grey-area streams - ones that may or may not move debris - is very prevalent. How do we now handle "gullies" that may contribute to a road or blowdown-induced landslide?

Eugene's work addresses the many aspects of hydrology and logging in a predominantly "rain" drainage. He acknowledges that in higher elevations or inland drainages rain-on-snow events could significantly alter these aspects (peak flows) of hydrology.

- From our viewpoint, we are very concerned with rate-of-cut influences on snowmelt, and, therefore, feel more study on this subject is required.

B. Stream channel morphology changes since logging (L. Powell)

The logging of Carnation Creek has resulted in significant changes in stream channel morphology. These changes are reflected in streambank erosion, increased streambed fluctuations, and changes in pool configuration.

Leave Strip Treatment

The leave strip treatment portion was least affected, although the sections showed increasing disturbance as you approached the intensive treatment area.

The data for this area seems to imply that if we wish to maintain stream integrity, we should be opting for the leaving of some streamside timber.

- An undisturbed leave strip would undoubtedly create considerable discussion among those people involved in timber harvesting. At present, we are not requesting complete undisturbed leave strips very often (exceptions do occur for recreational fishery buffers, elk leave strips, and difficult side channels).

Intense Treatment Area

As one might expect, this area was seriously impacted. The channel changes in these sections have, in fact, progressed into the leave strip areas.

- The results of this area would certainly direct us away from the use of this type of treatment in other similar situations.

The logging treatment in this area has altered the stream channel morphology through the disturbance of the streambed channel and streambanks through the felling into and yarding of timber from the creek.

Careful Treatment Area

The results of the careful treatment area are somewhat disturbing given the intent of the prescription, but perhaps explainable if one considers what the area has been exposed to.

We would like to think that normal streamside logging does not have the affect on the channel morphology as is evidenced in this area.

- Under normal practices there should be significant vegetation left along the streambank. This is not completely the case, and, therefore, the streambank may have lost some of its stabilizing capability (seed alder were felled after logging a "few" leaners felled across and yarded out; introduced debris was removed, but stable debris was not).

- This departure from "normal procedures" could have contributed to the addition of debris into the channel, the destabilization of stable instream debris, and the reduction of streambank stability.

- This aspect of falling a few alder and leaners may not have been particularly significant to the channel morphology in this case; however, it is something that we are continually faced with and does present us with problems.

In 1982 Toews and Moore felt that off-stream debris introduction may have caused the changes in channel morphology in this area.

- This could be from debris left along the stream margin that has washed into the channel, or, in the case of tributary 2600, debris that was not removed from the creek having moved into the main channel - thereby becoming a factor on the jam blowout just downstream. Apparently this log jam blowout occurred at flows of less than what it has withstood in the past.

- They also felt that the introduction of small organic debris and of small pieces of large organic debris subsequent to logging was one of the main reasons for morphology changes in this area.

- These changes, having been identified in 1982, have simply magnified themselves up until the present time.

- The fact that normal, careful streamside treatment apparently has not worked in this situation could have a dramatic affect on future streamside logging decisions.

- At this point in time two solutions come to mind:
  a. Go for larger leave strips; or
  b. Insist on debris being placed further back from the stream margins, and out of floodplain areas!

An important point that should not go unmentioned is the effects on not only this area, but the entire lower drainage, by the activities in the upper watershed.

- It makes little sense to spend a great deal of time and effort in the fish-bearing sections of a stream system if you do not apply the same care and consideration to the upper watershed portions.

C. A summary of the effects of streamside logging treatments on organic debris in Carnation Creek (C. D. Harris)

Organic debris is an important factor in the composition of a stream system. As we have seen in the previous paper, large, organic debris plays an important role in the determination of the stream channel morphology. Small organic debris in the stream can accumulate in jams, thereby inducing stream channel changes that can cause significant streambank erosion.

I would like to spend a short time discussing the management implications with regard to debris placement in streams, from a field perspective.

It has been stated that leave strips provide the greatest stability and future source for large organic debris; that section of Carnation Creek has been the least impacted.

- A question that we ask ourselves with this form of treatment is, how many trees are enough along the streamside?

- We know that too many induce blowdown; now it would appear that not enough can cause problems with the stream also.

- As a field person, I am concerned with our lack of information with regard to vegetation left along a stream. The suggestion is for "some" trees to be retained; but from here the questions start:

- How many trees?

- What species (alder, coniferous, or both)?

- How big should they be?

- Can a certain age of second growth suffice?

- I feel that this type of thing requires further clarification.

The fact that the streambank erosion in the careful treatment area was thought to be caused by the washing of small debris from the stream margins and floodplain areas raises some interesting concerns.

- There is a large amount of streamside logging taking place on the coast. A good falling job usually keeps all (nearly all) of the tops and branches up on the stream edge. If this is now being indicated as a major concern to stream managers, I can see some problems arising in the company's willingness to clean back debris from the stream margin.

- In addition, we just simply cannot get out on every block

- To try and assess where the stream might flood; and

- To return to inspect these areas after yarding.

The most frequent problem that we face, is the request for cross-stream yarding over steep gradient streams whose potential to move debris may or may not be readily apparent.

- A large number of these situations legitimately require some cross-stream yarding in order to harvest the timber, while a few are usually just related to convenience for the company.

- We then, of course, get into the ongoing problem of degree of stream cleanup. There is always much discussion on the terms of reference for cleanup in these situations:

- All debris (both large and small),

- All large debris, no small,

- All small debris, no large,

- No debris at all.

- Quite honestly, sometimes I do not think that we really know what is best in these conditions.

- The cost factor in both monetary and environmental terms can be staggering.

- I feel that there is a need for more work to be done on the aspect of debris management in smaller high gradient streams, and Carnation Creek would appear to give us a good place to do it.

In conclusion, I would say that the studies have certainly been worthwhile. I do feel, however, that further work with regard to some of the points I have raised should be instigated.

RESPONSE BY TOM PENDRAY, DEPT. OF FISHERIES AND OCEANS

Introduction

Like Bob, I have tried to look at and respond to the results presented in terms of how they may be applied in my day to day work as a haibtat manager.

I will respond briefly to the results and then ask some questions regarding the applicability of the results to other areas - particularly the central coast, north coast, and the northern interior.

Results

1. The main point re-emphasized by Dr. Hetherington's findings is the prominent role of roads in causing changes which are potentially harmful to the stream environment.

Roads have been shown to affect slope hydrology by accelerating runoff and increasing sediment levels. Diversion of surface runoff by roads may be a major factor in triggering slides and torrents.

There has been an increase in peak flows in small watersheds probably due to compaction from road surfaces. Other studies have also indicated the role of compaction from roads and landings in increasing peak flows.

All these findings re-emphasize the improtance of properly locating and constructing roads and the importance of minimizing road surface area as much as possible.

2. Dr. Hetherington's slope hydrology findings also have implications for development of improved roads building techniques - methods to avoid intercepting subsurface flows, etc. Techniques such as "double-binding" to minimize cut and fill volumes should probably be utilized to a greater extent than they are at present.

3. The increase in ground water levels in the valley bottom following logging - as noted by Dr. Hetherington - may improve the possibilities for enhancement of side channels. Perhaps this would provide some mitigation for detrimental logging effects.

4. In terms of stream morphology and LOD, it appears that results are little changed from those of the Toews and Moore report of 1982. The improtance of streamside vegetation both for bank stabilization and for future LOD input is re-emphasized.

   Buffer strips are shown to be important when they are windfirm. Perhaps more work needs to be done on design of buffer strips for windfirmness. For example, selected logging has been used to produce a "feathered" effect along buffer strip edges, rather than straight lines of even-height timber.

5. There is also more work to be done on potential mitigation and enhancement techniques of adding LOD to debris - deficient streams.

6. I am particularly interested in hearing how these observed changes in channel stability have affected gravel quality - processes which are directly linked.

Applicability to Other Areas

I'd like to close by asking some questions regarding the applicability of the results to other areas.

For example on the north and central coasts we have many more watersheds with potential rain-on-snow events. Carnation Creek has shown little impacts on peak flows from 40% harvest - but how does rain-on-snow affect acceptable harvest rates and timing?

In many cases we are delaing with less stable surficial materials - how does this affect stability and sediment results?

In many cases we have different species compositions - systems dominated by sockeye, chum and pink, which are perhaps more limited by gravel quality and availability. Perhaps LOD is not as important in these situations. Species specific interpretations will be required.

QUESTIONS
SESSION 1: RUNOFF AND THE CHANNEL ENVIRONMENT

Moderator: D. Handley

MR. WILFORD: Dave Wilford. A question for Eugene Hetherington.

It has to do with the landslides below roads, and since I walked one of them with you, I have some questions that you didn't bring out. You made it seem as though the failure was due totally to road runoff (surface runoff) running across the road and down the hill slope, but I thought we observed a bedrock crack that was intercepted by the road ditch and that the ditch water went down through the crack and then down a hill and a whole lot of pressure built to a point where there was a failure.

DR. HETHERINGTON: I didn't want to complicate my presentation. I feel from looking at all the factors that there were a number of reasons why those particular sections of slope failed. But I still believe that the ultimate triggering factor was that surcharge of water coming from the road, and my reason for that is I put a number of ground water well piezometers around the slide and did another winter's worth of measurement correlating them with nearby sites which I had running at the same time the slide occurred.

And what we found during one major storm that winter was when the rainfall intensity reached a certain point, that the water spilled over. There was a sudden jump in the water table at that point which made me feel that that was a probable triggering factor. But certainly Dave alluded to the way the bedrock slopes from the upper part of the road could have brought additional water down to that site, and added to the factors that caused it to go. We could debate which is more important.

MR. WILFORD: Okay. My only point for mentioning that was that I worked in Carnation Creek before logging, and I reckon the area was quite stable, and after years of looking at landslides I have never seen a similar event like that. So it's just that point of Bob Willington's that you can't forecast all problems.

MR. HOGAN: Dan Hogan. I have two questions actually, the first for Les Powell.

I'm curious about the controls. If I'm not mistaken, Charlie Scrivener mentioned control reaches. Given the variability of results and particularly the careful treatment reach, can we gain anything from the control basins?

MR. POWELL: We might be able to get some information from watershed "C" in that it is located at 1600 meters up the creek, and it's included in study area 5. As far as I know on the later maps we can isolate the effects on the side channel or we can measure the changes that have occurred there both in debris and channel form. On the earlier maps there will be a problem with missing data because I don't think that the surveys continue across from the hub lines out over the side channel, which is a tributary coming down from a control watershed.

MR.HOGAN: But your feeling is that there were changes in that control group that might shed some light on the other reaches?

MR. POWELL: I couldn't say about the channel itself because I haven't looked at it, but there are visible changes in the amount of debris in that side channel.

MR. HOGAN: Just one quick second one to Cathy Harris.

We found on the Queen Charlotte Islands that large organic reorientation was critical to the form. So I'm really interested in your complexity principle. What I wondered about is did you check the cross correlation of the variables and consider that larger piece volume would lead to larger, greater depths? In fact, all of your variables are intercorrelated, so would that influence your relationship?

MS. HARRIS: I have yet to do it but would like to weigh each of the factors used in measuring debris complexity index, but definitely I feel that debris orientation has got a lot to do with determining when the channel could change. You could see by the change in orientation that there would be a possibility of that piece blowing out or leaving the reach. So orientation has got a lot to do with stability.

MR. HOGAN: Yes, I would be very interested in the weighted values.

DR. HARTMAN: Gordon Hartman. I'd like to just make a comment. I think about three of the panel people got on to the topic of the significance of peak flows and questions about whether or not there were changes in peak flow, and I understand that and I understand the importance of that in the matter of scheduling that Dave Toews referred to.

I think that notwithstanding all that, it's really important for all of us to keep in mind that in systems like Carnation Creek there is such a variability, such a lot of hydrological energy in those kinds of drainages that if there are changes in other conditions in the system, with or without alteration of peak flow rates, there's enough variability and instability in flow to set everything going even though you may not alter peak flows.

So while it's important, I think, to think about this rate of cut story, remember there is already enough energy there to really turn things loose, if there are other alterations made in the system.

I wanted to answer a question, if I could, I think for Bob Willington. He asked whether or not there were any ways that we could predict stability, and I could get together with him later and give him a paper by Mason Bryant in Alaska, in which Bryant did some analysis and described some parameters, I think, that provide some measures of stability and large debris in streams.

Now I get to a question, and I'll be finished. I understood Eugene that you said, or someone quoted you as saying, there was only one rain-on-snow event. Can you tell us if there was only one rain-on-snow event or whether there was only one that has been analyzed?

DR. HETHERINGTON: Yes, I think the latter comment is appropriate. There was one major rain on snow event where we know for sure that there was snow prior to the occurrence of the rain event, and we have some estimate on how much snow there was. Over the life of the history of the watershed there has been snow almost every year at higher elevations at the back end of the watershed.

What was significant about that 1982 event is the whole watershed had about a foot of snow when the rain started and that made all the difference, and I'm not aware of any other storm system where that much snow was present over the entire watershed.

DR. CHENG: My name is Jack Cheng. I'm the hydrologist for the Ministry of Forestry and Lands in Kamloops.

Firstly, I'd like to ask a question for Les and Cathy. Would you care to place your confidence limit in regard to those conclusions you made? 95^percent, 90 percent or 85 percent or 80 percent?

MR. POWELL: I guess I didn't get the question.

DR. CHENG: When you are making your conclusion, just generally would you care to make a statement with regard to your conclusion? You have 95 percent confidence limit, or 90 percent confidence limit, or 85 percent or 80? Just in general.

MR. POWELL: I'll say about 95 percent.

MR. HANDLEY: Cathy, you say the same?

MS. HARRIS: Oh, yeah, I agree 95 percent.

DR. CHENG: The point I try to make, the last, will be for Eugene. I believe that based on some of his statements we're using the so-called paired-watershed analysis, and when Eugene makes his statement with regard to whether there is a change or no change in supplying your peak flow or stream flow as a result of logging, he probably based it on the 95 percent confidence limit.

And my question is that I would offer a certain alternative to that for drawing management conclusions. Do we really need 95 percent confidence limit? Maybe for Eugene's case some observations which are considered nonsignificant change based on 95 percent confidence limit may be considered a significant change if you lower down your confidence limit to 90 percent or 85 percent. And, of course, after we lower down our confidence limit to 90 percent or 85 percent, we can discuss the implication of the result based on the context of the results of other similar studies - that means the studies with similar design, with similar hydrological environment.

Thank you. That's only my own observation.

DR. HETHERINGTON: I would probably agree with Jack. Scientists like to be as close to certain as they can before making the statement about change, and so this 95 percent confidence limit means that we have eliminated almost all doubt that there was a change, but in reality there are changes that occur well before that limit, and in a practical term maybe we should be considering some lower threshold of confidence limit just so we can know that, in fact, that there are changes occurring.

MR. TOEWS: I'd just like to make another comment. This is a before and after design where we have five years of study before, five years of study during, and five years of study after. And in the debris work, each year was treated as a separate number, and we did "T" tests, quantities of debris and things like that before and after. And I think one of the strengths of the study is that we do approach the kind of confidence limits that scientists like to get, because it is a longer study. Most other people do a once before and after and usually you can see a story of what is happening if, let's say, you re-examine an area a number of years after logging.

But I think we are quite a bit stronger in terms of confidence numbers. The trouble is you have to go to volumes of debris and number of pieces which are just an intermediary to the ultimate biological changes or physical changes that you are really interested in, and that's why this complexity index is interesting.

MR. MORRISON: Doug Morrison. I have a question for Eugene.

I'm wondering along the lines of, I think, what Bob Willington was commenting on, and it's bothering me as well. When you look at the post logging years and the peak flows that occurred during those post logging years, I'm wondering if there's any way we can evaluate whether it was an episodic event, possibly as Gordon alluded to, set up by some of the things that occurred in the watershed as a result of logging, whether they were as a result of logging or a result of strictly the size of the flows that occurred as a result of post logging situations or perhaps a combination of logging and the size of the flows.

And I'm wondering, Eugene, if we could look at the precipitation records prior to when the study was initiated and find out when the last similar size stormed occurred in that general area? Given that logging hasn't really affected peak flows, can we look at a correlation between earlier precipitation events to try and determine when the last large discharge occurred in the watershed, and knowing how stable the channel or what the channel looked like at the beginning of the study - my interpretation is that it was fairly stable - get some idea as to how long it had been since that channel had experienced a similar sized discharge?

DR. HETHERINGTON: I believe we could do that, and I'll take that under advisement. There is a longer term precipitation station at Bamfield, and we do have flow records on the Sarita River which is affected by lakes. But it might give us that kind of indication. It's a worthwhile suggestion.

MR. SCRIVENER: Charles Scrivener. Essentially we don't even have to go back to concern ourselves that much with the unusual or what might be unusual events in '84 or in '82. We simply extended what Toews and Moore have already found, and they were reporting based on a much smaller flood in 1978. The major changes occurred after 1978 in flows that were within the pre-logging range. What they have reported since 1982 is simply an extension of what we've already observed.

MR. BUSTARD: My name is Dave Bustard. I've got a question for Eugene, with possibly some help from Les.

I'm going to change the topic a little bit from peak flows and ask Eugene to comment a little bit on changes on low flow, not just the measurements at the weir but the amount of surface water that is available in the channel given some of the changes that have been described. Are we looking at increased surface areas or reduced surface areas after logging?

DR. HETHERINGTON: I think Les will have to comment on that from the survey data.

MR. POWELL: I think we've seen some buildup of sediment downstream in the bottom end of the intense treatment, and there has been periodic dewatering during the summer months. And if I look at the flow records that are available for, I think, 1985, there was a continuous period of about two months when "B" weir was registering around 1 C.F.S. flow for those two months. And during that time, the maps that I have indicated the water level in the channels at the given flow at "B" weir, and there were quite extensive sections of the creek where there was no apparent surface flow. There were pools and obviously whatever water was flowing was subsurface.

Section 8, which is where that big debris jam built up, and this would be after the major flood, that whole section - although the map shows direction of flow and it shows a wetted perimeter - well, there was no water in there during the five days we did the survey. It was all subsurface, and where the fry were during that point in time, I don't know. Obviously, they weren't in that section.

It's quite interesting, as Charlie pointed out, that the limit to fish was up in the canyon. That large debris jam was, in fact, passable by fish, and yet it's the sort of structure when you look at, you think that there wouldn't be anything going past it.

MR. POWELL: I can't give you a hard and fast answer, but I think in view of the buildup of sediment, the surface area would probably be about the same given that the channel has widened. But, in fact, the channel has changed its depth as well. So you probably have less usable area for the fish.

MR. BUSTARD: Is there going to be any sort of effort to have a quantitative comparison before and after this phenomenon?

MR. POWELL: Well, we could. We could calculate the surface area in each of the study sections by each year.

MR. BUSTARD: This seems to be an important question. I know that ten or fifteen years ago we always used to hear from the old-timers that streams used to dry up after logging. Yet the hydrologists always would contradict this by saying that, in fact, there is more water in the stream. Maybe we've got a bit of an answer from that question from some of the stuff from Carnation Creek as to what action may happen.

MR. DE LEEUW: Yes, my name is Dionys de Leeuw. I found your results on large organic debris in Carnation Creek quite interesting. I'm wondering whether they're applicable to streams that are much larger than Carnation Creek?

In the Charlottes we have an experience where we have fairly decent sized streams, and we have huge spruce trees, and I'm really worried that with the removal of spruce trees we're going to see no input of large organic debris to the streams. And I'm wondering whether it's possible from the research that you've done and whatever else is available, are there management strategies where a larger kind of debris can be developed? Because I think we really need it, especially in the Charlottes, and I guess I'll ask Powell and Cathy.

MR. POWELL: The first question I'd have to ask is what size of system, Carnation Creek represents a 10 square kilometer drainage.

MR. DE LEEUW: The Yakoun is the largest drainage in the Charlottes, and it's about 450 square kilometers, by far the largest system on the Charlottes.

MR. POWELL: And how much natural large debris is there already?

MR. DE LEEUW: There is a tremendous amount of large organic debris, but some of it is becoming extremely mobile because of erosion, bank instability, and so on in some areas.

MR. POWELL: And your concern is that there isn't a new source to replace that?

MR. DE LEEUW: Indeed, yes. I'm thinking about the next 50, 60 years. You know, large organic debris is the key to fish in the Charlottes, at least that is my impression, and I'm wanting to keep that stuff in the stream. And I want to have a continuous supply in the Charlotte's streams, and yet that timber along the creek is the most valuable timber product on the Charlottes. So it's a very well structured conflict.

MR. POWELL: Well, yes, this has been mentioned by several people already today in that there is need for work on leave strip composition and width. We mentioned how wide the strip should be.

I gather at Carnation Creek, and I'm not familiar with the total prescription before logging in terms of the width of those strips, but they experienced blowdown in the upper part of the leave strip treatment and had to do some further logging that is considered to contribute to the problems that are occurring there, compounding the downstream effects. And that's one question that I put in my management implications, in my written paper going into the proceedings, that there needs to be more work done on that, and I guess that's true of the large organic debris.

You would have to look at whether you can start to anchor some of that large debris you feel is moving to make sure that it stays in place with the correct orientation, and there is some work going on in the Charlottes at the moment regarding the placement of large debris in some of the high energy systems that have been torrented to replace it, but there is nothing that I know of in regard to maintenance of large debris in a system like that.

MR. DE LEEUW: Thank you.

MR. HANDLEY: I believe we may get more of that tomorrow from our after dinner speaker.

MR. REYNOLDS: Phil Reynolds, C.F.S., F.P.M.I. I have a question basically for Eugene.

You mentioned there were four major debris torrents in 1984. Could you tell us more about when chronologically those occurred? What month of the year was it?

DR. HETHERINGTON: That was in January, '84.

MR. REYNOLDS: So all four events occurred in the same storm?

DR. HETHERINGTON: Yes, at the same time.

MR. REYNOLDS: I see, okay. And my other follow-up question is a general one for anyone on the panel or perhaps someone in the audience in that it may be more appropriate for Session 5.

I'm wondering if anyone has looked at the impacts either direct or indirect of the debris in the channel as far as the fish movements or utilization of various side channels? May I throw that out for food for thought?

MR. SMITH: Jeff Smith. I have a question about habitat enhancement that Cathy Harris alluded to in her talk this afternoon.

In your results relating rootwad and large organic debris complexity to numbers of fish, I'd like to maybe some other time talk more about how you got to that point of showing that regression between the two variables, but for now can you perhaps answer the question what do you believe to be the implications for habitat enhancement of your study results?

As an example of what I'm asking, if numbers of fish increase with complexity of the unit in place in the stream, what's the upper limit of complexity that we can hope for in order to optimize the use of habitat by fish?

MS. HARRIS: I don't think I can quote an actual number of logs and pieces of wood that you'd like to have. As I said before, I would like to weigh the factors of the debris complexity index, but I couldn't put an actual number on such as we'd like 40 cubic meters of wood per 100 meters of stream reach. I think when you start impeding the movement of fish in the creek, you're going to have too much debris, but it's very difficult to put a number on that.

MR. HAYWARD: Ron Hayward, Fish and Wildlife Branch. Basically we heard how the channel changed and how the amounts of large organic debris changed after logging in the intensive treatment areas and in the careful treatment areas where basically we're looking at some cross stream falling and yarding as well.

My question has to be how did – did anybody decide whether the disturbance of the large organic debris was from small organic debris or whether it was from the physical disturbance of falling across and yarding across; and if it was from small debris, what the source of that was, whether it was immediate within the stream itself and didn't get cleaned out or whether it was from something like a debris torrent or something like just an extreme high flood in removing it from a flood plain area?

And to me, you know, it's extremely obvious that large organic debris is a basis of fish production, and I want to know how I can maintain that in the streams that I'm going to look at, prevent logging across the stream or make sure that the small organic debris isn't going to get in there and disturb the large organic debris.

MR. POWELL: Well, I think during the logging phase in the intense treatment, some of the large natural debris in the channel was taken out at that time, and my understanding is that the natural debris, the small debris, was not cleaned out, and that material was left in and was highly mobile.

In the careful treatment, there was an effort made to remove all the introduced pieces of debris from logging. The natural material was left in place, and because I wasn't there, I'm assuming that the small pieces that were introduced were put up on the side out of the wetted perimeter. And up to that point, if you look at the chart over there, [see figure 1, Hetherington's paper] you can see they hadn't experienced very many large flows. I think the debris logging maximum flow is something like about 1200 plus C.F.S., and after logging they had flows in excess of 1500 C.F.S. So that type of flow afterwards would pick up material that was placed just outside the wetted perimeter and bring it back into the creek.

It was apparent from the survey crew's observation that after the torrent most of that material had been stranded upstream of the jam and hadn't reached down that far. It was only the sediment in the torrent material that got as far as the jam.

In my suggestions for management treatment, I am recommending that small debris be moved out of the channel and far enough back that it can't reenter. Now, that's going to require a little bit of guesswork in that if you look at the wetted perimeter and you can identify the wetted perimeter for reasonable peak flow, you may need to throw it another 10 feet further back. Since nobody is going to be able to predict what maximum flow the channel is going to have in the future, it's very difficult to say it should be at a certain distance. I think some judgment has to be used on the ground.

MR. HAYWARD: But basically we can say that management of small debris, like keeping it out of the main stream channel wherever it comes from, whether it comes through a debris torrent or whether it comes through on site or lifted off a flood plain, if we can keep the small debris from destabilizing the large organic debris --

MR. POWELL: -- then you're going to provide a channel with a better chance of maintaining its stability. You're not going to stop it changing, because obviously we saw changes where conditions haven't been altered by logging. So it is natural is that there will be some change. You want to minimize the effects of any treatments along the creek. As far as I know, the actual stream bank disturbance wasn't quantified during the logging to see what sort of impact there was on that.

And I think another observation that I make in my paper is the importance of the living root network along the stream bank which is going to include the components provided by mature trees. It's going to work on the stream banks exactly as it does on the hill slopes to provide the stability, and you've got to maintain that living root network to keep the stream banks in a healthy condition.

I alluded in my comments to the area that was lost of the stream bank, not to the volume of material that would be introduced, and I think that's an important point for the forest industry to consider: the amount of growing space that's lost in what is always referred to as the highest productivity sites. I mean, it was the high spruce sites in Carnation Creek, and in seven years since logging along the careful treatment section we've lost over a hectare.

MR. MILES: My name is Mike Miles, and people were asking about historical variations in precipitation and runoff. I have, in fact, analyzed that for the area of Barkley Sound and I can summarize that in a couple of seconds.

If you look at stream flow data from Sarita River, which is just along the coast, it is a lake regulated source likely to have less flashy flows than Carnation Creek, and there is data back to about 1948. There are four flows in the period around 1960, which are annual maximum daily flows. There are four flows, that are almost twice as big as any reported in the period of the Carnation Creek study. There is one flow that is probably 35 percent bigger than anything recorded during the Carnation Creek study. So, in fact, the Carnation Creek study has occurred during a relative period of small flows compared to those which occurred around the 1950 to 1960 period.

If you look at annual maximum 24 hour precipitation on the west coast, data from Bamfield and Bamfield East, the biggest single day event is about 1965 and it is about twice as big as anything that occurred during the Carnation Creek period.

Data from Pachena Point show the biggest single day rainfall total was about 1972, which would be in the vicinity of the Carnation Creek study, but again it's not much larger than the other stations.

What this does bring about or address is the fact that it's now well documented that annual precipitation, annual runoff in a period from about 1945 to present, is 10 to 20 percent greater than that which occurred between 1920 and the mid 1950's.

The question I've got for both Eugene and Les Powell is how do you think your results would change if you had been working in the 1920 to 1950 period when the annual precipitation and annual runoff was much less and the annual maximum flows and maximum 24 hour precipitation was also generally quite a bit less than it is now?

The second question I've got is that most of the results I've heard from Carnation Creek are looking at the effect of logging. It strikes me that you've got a unique data set here. The types of analysis which I would have expected to see would be using your data to estimate or to evaluate various formulas in computing things like time of concentration, Froude numbers, bedload transport formulas, are those types of assessments being done with your data; and if not, why not?

Thank you.

DR. HETHERINGTON: The response to that last question about Carnation Creek data is that the project has in a sense suffered by not having a full time hydrologist.

I came on to look at slope hydrology and to look at some of the flow data, but, in fact, there's still a lot of valuable information residing in our data bank, and if I live long enough, I might get to it. But I suspect that we may try to get some of that done through students. We're encouraging other people to look at the data base, but in a sense our real mandate was to look at the effects of the harvesting on the system, and we haven't dealt with expanding the information base in the way you suggest.

You had another question?

MR. MILES: Yes, Eugene, it was for both of you. It's to do with climate change, and we're in a much wetter than normal period now, so we are experiencing higher runoffs and higher discharges than in general in the area since the 1920/1950 period. How do you think that would effect your results?

DR. HETHERINGTON: Well, my first reaction from a hydrologic point of view is I wouldn't think it would change it all that much. We still have a highly variable system in terms of storms, and our annual maximums are not necessarily related to total precipitation. For example, you can still get stream bed movement in a low year.

And I don't know how far back you go, but the stream has meandered back and forth across the flood plain historically. So it's gone through a lot of changes, and we're in one of those periods where it may have stabilized itself for awhile and man has come and destabilized it, but my assessment of the processes are that those processes hydrologically speaking were still operating, and I can't see it would be a whole lot different myself.

MR. HANDLEY: Les, do you wish to tackle it?

MR. POWELL: In terms of the data that we've got, we haven't looked at estimating bedload movement, but it would be possible from examining the volume of material scoured and deposited in each of the study areas to get if not an accurate amount, a quantitative estimate of the types of bedload movement.

Charlie alluded to the fact that because the weir pools fill up and are cleaned out, there are estimates of how much material comes into that section in one particular storm event and has to be moved, but I don't think there's been a great deal of work done on bedload. Bruno Tassone is addressing that tomorrow.

MR. HANDLEY: Thanks.

MR. POWELL: On the second question in terms of what sort of changes are seen, actually I shudder to think what would happen if the area had been logged in the 1920's and we were going in and measuring it based on what we know about the techniques of logging that were done in that day. They probably would have gone straight up the creek with a cat and taken everything out. We'd have a major highway there.

If the same logging techniques that applied in that year are looked at, I think we've got the leave strip treatment there that's experienced some pretty massive flows without showing a great deal of alteration. Not all of that is confined to the canyon section where there's bedrock control. So I think the system could probably have accommodated that.

I guess you could also ask the question, why was the area not logged. They were logging up the Alberni Canal, and obviously it wasn't a suitable site to get into for the type of equipment they used.

MR. HARDING: My name is Ted Harding, and I want to ask Eugene a couple of questions.

Eugene, is the careful treatment area the uppermost treatment area in Carnation Creek?

DR. HETHERINGTON: Yes.

MR. HARDING: Okay. Now you showed us a slide which is one of those '84 torrents.

DR. HETHERINGTON: I call it the canyon blowout.

MR. HARDING: Right. Now, did that material move from the canyon into the careful treatment area?

DR. HETHERINGTON: Yes.

MR. HARDING: Okay. Well, the first question then is obviously what changes occurred in the careful treatment area, and they all can't be attributed to streamside treatment, or can they? Have you looked at that?

DR. HETHERINGTON: I personally haven't been involved in looking at what happened in the channel. I have to deflect that to Les.

MR. POWELL: Well, my feeling is that the careful treatment stops at the canyon and then we start going back into the equivalent of a leave strip. Along the canyon walls they left that strip there.

We have definitely seen downstream effects into the careful treatment area that would probably not have happened if we hadn't had the torrent, but as several people have alluded to, we had no indication that the watershed was unstable and that there would have been a torrent.

So in presenting the results that I've got that indicate increasing stream widths there, we're dealing with what actually happened, not what was anticipated to happen. And I don't think it's unfair to say that this has gone on as long as we recognize that there are some compounding effects, and it's not all related to the careful treatment.

The figures that I gave predicting the amount of stream bank that's eroded, I think, are even more realistic when you consider the fact that that section of the stream has been torrented. If there was only the development of the stream channel around the debris jam at section study area 8, then it would not be fair to extrapolate those results back up to the treatment area, but because the upper part of the treatment area has been torrented as well, then it gives a much more realistic picture of what would happen. That is what it was all about.

MR. HARDING: My second question is simply the three treatment areas Eugene mentioned, do all three treatment areas have the same capacity for later migration of channel? In other words, what I'm saying is, is it possible one of those could have moved more laterally just because of the nature of that channel compared to the other ones? In other words, more erosion, more movement of debris on a natural basis?

MR. POWELL: Well, I think the leave strip treatment downstream probably has the least opportunity to provide lateral channel movement because of the bedrock controls through that lower canyon, and undoubtedly in the careful treatment area the ability or the chance of the channel migrating is influenced considerably by what's coming out of the canyon and the middle section which is where the intense treatment went on. That's a flood plain that varies in width, so there isn't the opportunity for it. And we obviously, unfortunately, don't have aerial photographs that go back long enough to show how that channel has changed.

MR. HANDLEY: I need some clarification. I don't know about other people, but I'm now a little confused, Les.

If I understood the question correctly, the implication was that the so-called careful logging perhaps suffered an unfair fate because it happened to be next to the canyon, and the results from it are worse than what one would have expected from the intense logging area. And I thought I heard you saying even if you tried to make allowances for that, that that would still be your answer. So by implication then, the intense logging system is better than the careful logging system?

MR. POWELL: No, I didn't mean to give that impression, if that's what you got. No, what I wanted to allude to was the fact that what I reported and what was referred to by careful treatment has arisen from what's happened, and in view of the fact that's what happened, it's very difficult to now say this is what should have happened in here if everything went smoothly with the careful logging treatment and we didn't have this extra big flow that came down and the torrent that occurred.

SESSION 2:
SEDIMENT AND GRAVEL

Moderator: R. Morley
Ministry of Environment and Parks

SEDIMENT LOADS FROM 1973 TO 1984
08HB048 CARNATION CREEK AT THE MOUTH, BRITISH COLUMBIA

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INTRODUCTION

Water Survey of Canada (WSC) has provided data on streamflow and sediment loads since 1972 through participation on the Carnation Creek Steering Committee and Working Group. In 1972, WSC was requested to take over operation of the main hydrometric station at B-weir and investigate the sediment data requirements at this site.

WSC involvement consisted of collecting and processing the flow data at B and E weirs and suspended sediment and bedload data at B-weir for publication in the annual Surface Water Data - British Columbia and Sediment Data — Canadian Rivers publications.

This paper summarizes the results of the sediment data collection program between March 1973 and March 1984.

All data are presented on the basis of the water year (October 1 - September 30).

METHODS

Hydrometric data have been collected continuously since December 1, 1972; bedload and suspended sediment data were collected between March 1, 1973 and March 31, 1986. All data were collected at the B-weir site.

Suspended sediment samples were collected with a PWS-3 automatic pumping sampler and DH-48 and D-49 depth-integrating (D.I.) samplers. The DH-48 sampler was used during wading measurements and the D-49 sampler was used from the cableway under high flow conditions. A PWS-3 pumping sampler was programmed to take samples at various water stages through an intake line. The intake was located approximately 3 m from the right bank. Depth-integrating suspended sediment measurements were obtained by sampling through the water column at five verticals across the channel. The sampling cross-section was located approximately 20 m upstream of the pump sampler. A discharge weighted concentration (Ca) was determined for each D.I. measurement.

A pump adjustment factor was computed as:

$$k = \frac{Ca}{Cp}$$

where: k = pump sample adjustment factor
Ca = cross-section concentration
Cp = pump sample concentration

From a number of these measurements a correlation was obtained which was used to adjust the pump sample concentrations. The adjusted concentrations were plotted against time on a copy of the stage recorder trace and the suspended sediment concentration curve was reconstructed.

The curve was digitized and the daily load calculated by:

$$Q_s = \bar{c}\,\bar{Q}\,k$$

where: Q_s = suspended sediment discharge, tonnes day^{-1}
c = mean daily concentration, mg l^{-1}
Q = mean daily flow, $m^3\ sec^{-1}$
k = unit conversion factor of 0.0864

Bedload samples were collected from the cableway and metering bridge 30 m upstream of B-weir. The Arnhem and basket type of bedload samplers were used. Two to three samples were collected at each of five verticals, sampling times ranged from ten seconds to three minutes.

Bedload transport rates in this paper have been calculated by:

$$Q_{BL} = \frac{\sum_{i=1}^{n} \frac{W_{BL}\,E}{t\,w}}{n}$$

where: Q_{BL} = Bedload transport, kg $m^{-1}\ min^{-1}$
W_{BL} = weight of material trapped by the sampler, kg
t = sampling time, min
w = sampler width, m
E = sampler efficiency
n = number of samples collected

RESULTS AND DISCUSSIONS

Streamflow

Table 1 summarizes the annual and peak discharges observed. The four highest peak discharges and four lowest annual discharges occurred in the logging and post logging periods.

Suspended Sediment Load

From Figure 1 it can be seen that sediment loads in Carnation Creek are seasonal in nature. The majority of the sediment load is transported between October and March; this coincides with the high discharge months in the watershed.

A summary of the published annual loads appears in Table 1 and is depicted graphically in Figure 2. A double mass curve of cumulative load versus cumulative discharge is shown in Figure 3. There is no obvious inflection in this curve, through the observation period. The relationship between annual load and annual discharge is shown in Figure 4.

Suspended Sediment Concentration

Annual rating curves were developed for both the rising and falling stages of storm hydrographs and are shown in Figures 5 and 6. Table 2 lists the parameters of the power equation $y = a\,x^b$ for these curves.

The rating curves normally had a wide scatter of points, typically one log cycle. There is no discernible pattern to the curves which one could associate with the logging program.

Figures 7 and 8 show discharge and supsended sediment hydrographs for various storms over the period of record.

In general, they depict similar response patterns as Beschta (1983) found in an undisturbed Oregon coast stream.

i. increased stormflow, normally increases sediment concentrations

ii. the steeper the hydrograph slope, dQ/dt, on the rising limb, the greater the concentration

iii. sediment concentration decreases with each successive storm as long as peak flows do not exceed previous ones, i.e. suspended sediments in Carnation Creek are supply limited.

Hysteresis curves were prepared for some of the storm events. Most show a similar pattern of higher concentrations on the rising limb of the hydrograph than the falling limb.

During the study period only one set of suspended sediment samples were analyzed for particle size distribution. This was from a D.I. measurement on November 7, 1978 at an instantaneous discharge of 27.5 $m^3\ sec^{-1}$. The sample consisted of:

36% fine sand	(.062 - 1.0 mm)
55% silt	(.002 - .062 mm)
9% clay	(< .002 mm)

Table 1. Streamflow and sediment load summary: Carnation Creek at the mouth.

Water Year	Annual Discharge dams^3	Peak Instantaneous Discharge $m^3 \cdot sec^{-1}$	Annual Suspended Sediment Load tonnes
1973/74	37,400	19.3	403
1974/75	23,700	22.3	146
1975/76	37,000	31.4	309
1976/77	19,490	34.8	127
1977/78	22,700	24.6	156
1978/79	16,570	43.9	180
1979/80	22,780	23.4	233
1980/81	27,700	43.1	244
1981/82	26,700	50.0	190
1982/83	23,400	36.2	323
1983/84	29,500	65.0	271

Bedload

Bedload rating curves (Figures 9 and 10) were developed based on rising and falling stages of storm hydrographs. From the curves it appears that significant bedload transport (>1 kg m^{-1} min^{-1}) does not begin until the discharge reaches 10 m^3 sec^{-1}.

An estimate of the total bedload transported was made based on records of the volume of material removed from the channel in the vicinity of B-weir. Volumes were converted to weights assuming a unit weight of 1.6 tonnes m^{-3}. Removal first occurred on January 11, 1973 and it is assumed that this brought the area to a zero base. Table 3 lists the cumulative bedload discharge and the corresponding cumulative suspended sediment discharge. Bedload figures are considered to be conservative as the weir has a low trapping efficiency. From the results it appears that the bedload comprises at least one half of the total load. Bedload transport would appear to be one of the major channel forming mechanisms in this watershed.

REFERENCES:

Beschta, R.L. 1981. Patterns of Sediment and Organic-Matter Transport in Oregon Coast Range Streams. Erosion and Sediment Transport in Pacific Rim Steeplands (Proceedings of the Christchurch Symposium, 1981) I.A.H.S. Publication No. 132: Page 179-188.

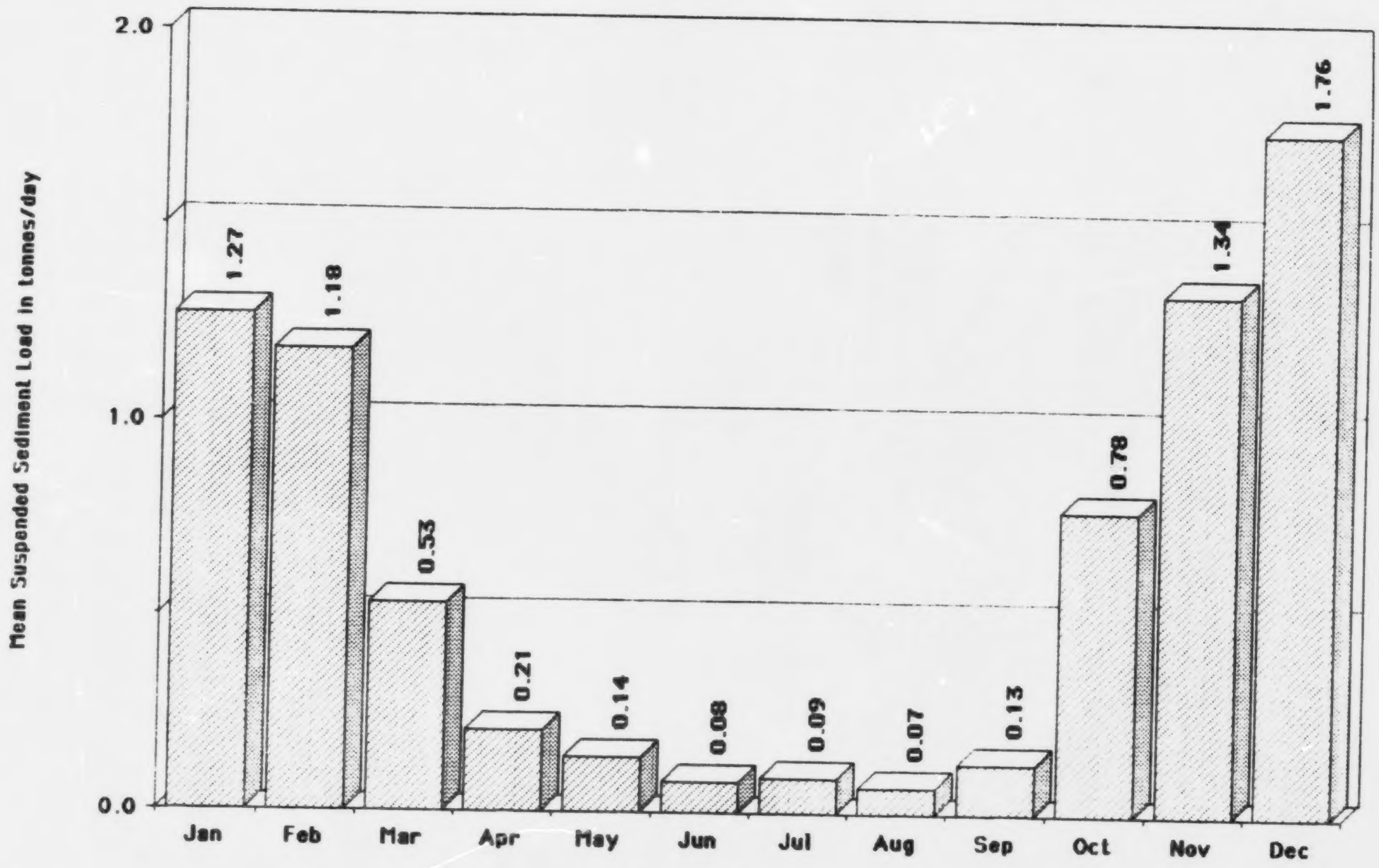

Figure 1. Carnation Creek near the mouth. Mean monthly suspended sediment load.

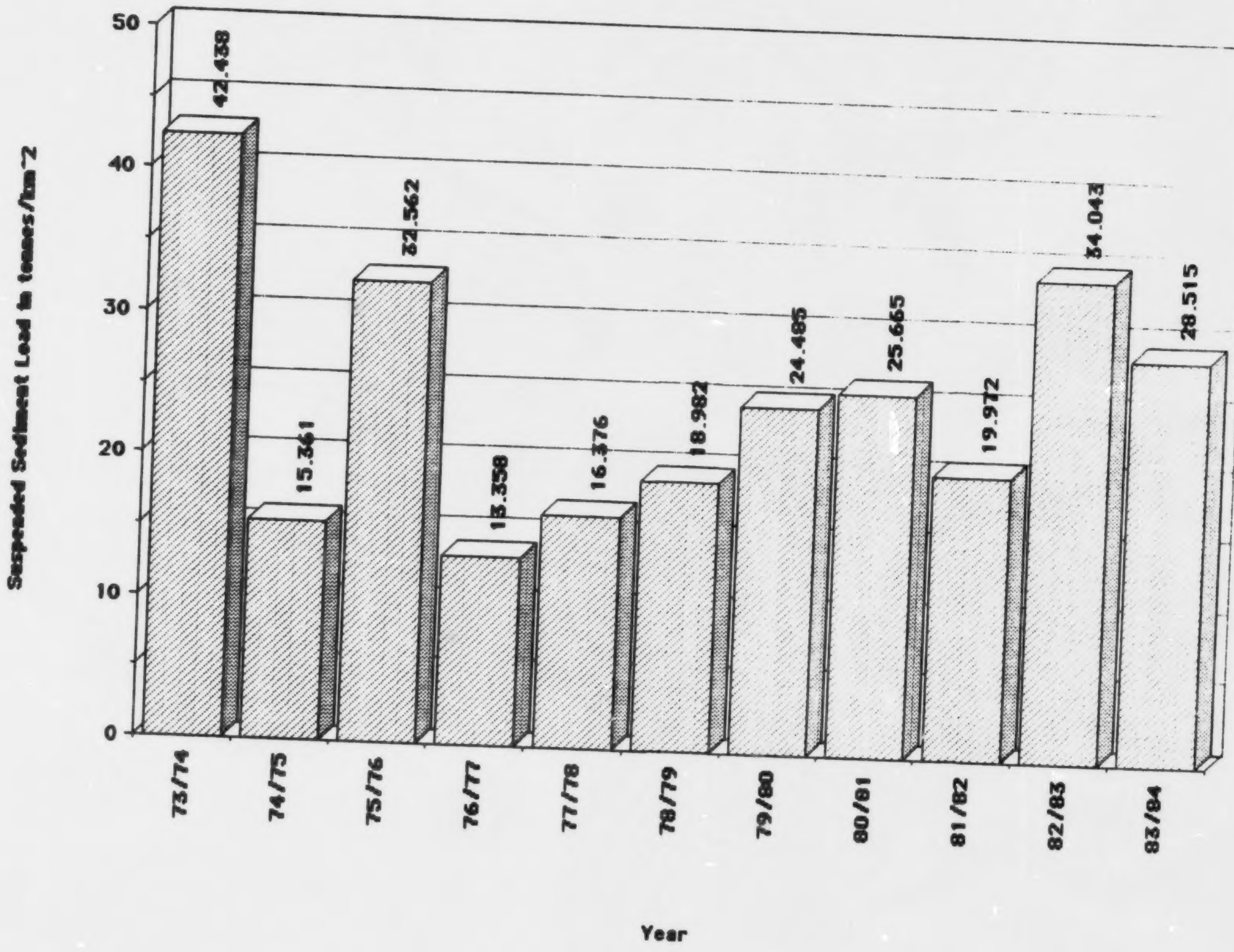

Figure 2. Carnation Creek near the mouth. Annual suspended sediment load.

Table 2. Descriptive statistics of rating curves, $y=ax^b$. Carnation Creek at the mouth.

Water Year	Number of Samples n	a	b	Correlation Coefficient r
		Rising Stage		
1973/74	152	1.3866	1.1296	0.63
1974/75	66	1.7699	1.0742	0.76
1975/76	215	1.0120	1.2891	0.73
1976/77	51	1.7110	1.0891	0.70
1977/78	94	2.7063	0.8040	0.59
1978/79	62	0.3125	1.9161	0.85
1979/80	78	3.7893	0.9453	0.47
1980/81	42	6.5270	0.3740	0.26
1981/82	80	3.1781	0.7011	0.57
1982/83	92	5.6215	0.6088	0.55
1983/84	47	2.1700	0.8138	0.62
		Falling Stage		
1973/74	131	0.7827	1.3526	0.72
1974/75	68	0.7372	1.2513	0.88
1975/76	201	0.7955	1.3177	0.73
1976/77	84	1.1570	1.0333	0.74
1977/78	131	2.3210	0.7949	0.58
1978/79	74	1.8440	1.1947	0.59
1979/80	97	9.1408	0.4321	0.35
1980/81	41	4.6108	0.4940	0.39
1981/82	120	0.6664	1.3486	0.68
1982/83	88	1.6108	1.0490	0.66
1983/84	79	0.9945	1.1477	0.64

Table 3. Cumulative bedload and suspended sediment discharge. Carnation Creek at the mouth.

Date	Cumulative Bedload Discharge tonnes	Cumulative Suspended Sediment Discharge tonnes
February 7, 1973	477	318
July 25, 1975	784	574
September 22, 1976	1,005	889
November 27, 1978	1,280	1,277
January 20, 1980	1,892	1,507
August 15, 1980	2,137	1,574
January 24, 1981	2,442	1,773
Feburary 10, 1982	2,625	1,980
February 7, 1983	2,717	2,195
August 10, 1983	2,900	2,341
February 7, 1984	3,205	2,569

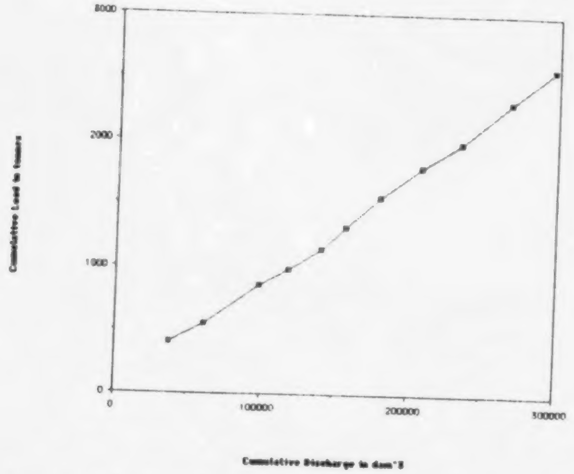

Figure 3. Carnation Creek at the mouth. Double mass curve.

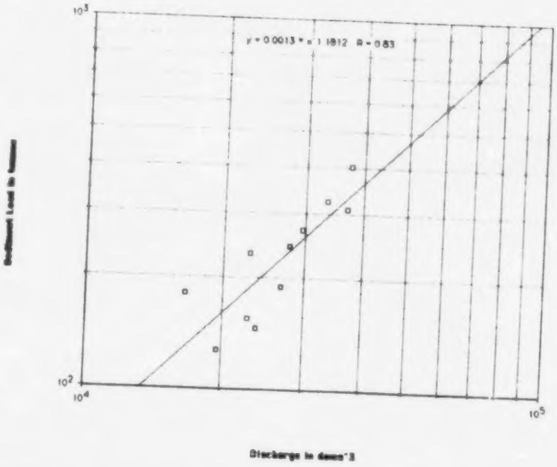

Figure 4. Carnation Creek at the mouth. Annual rating curve.

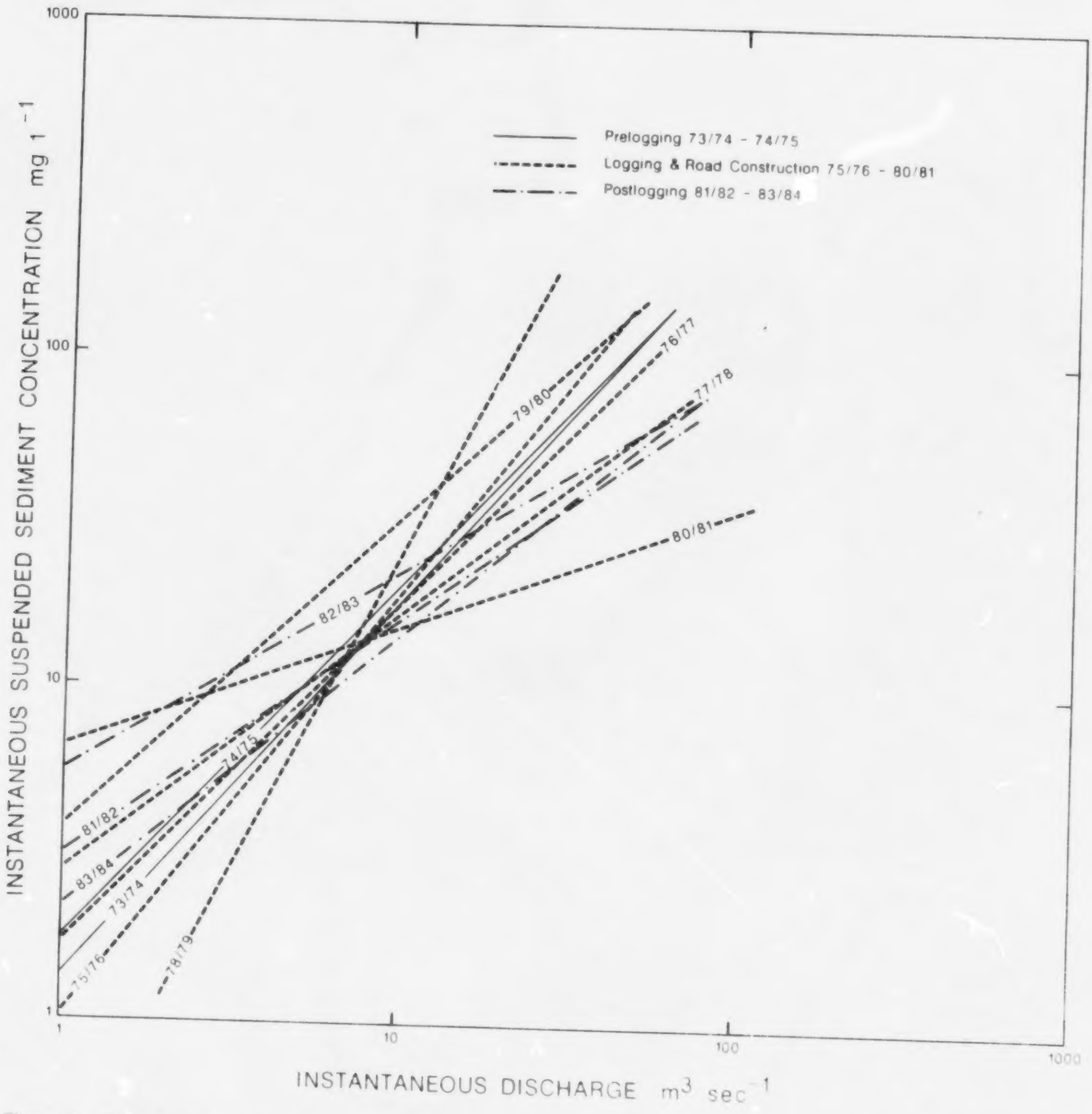

Figure 5. Carnation Creek at the mouth. Rising stage rating curves.

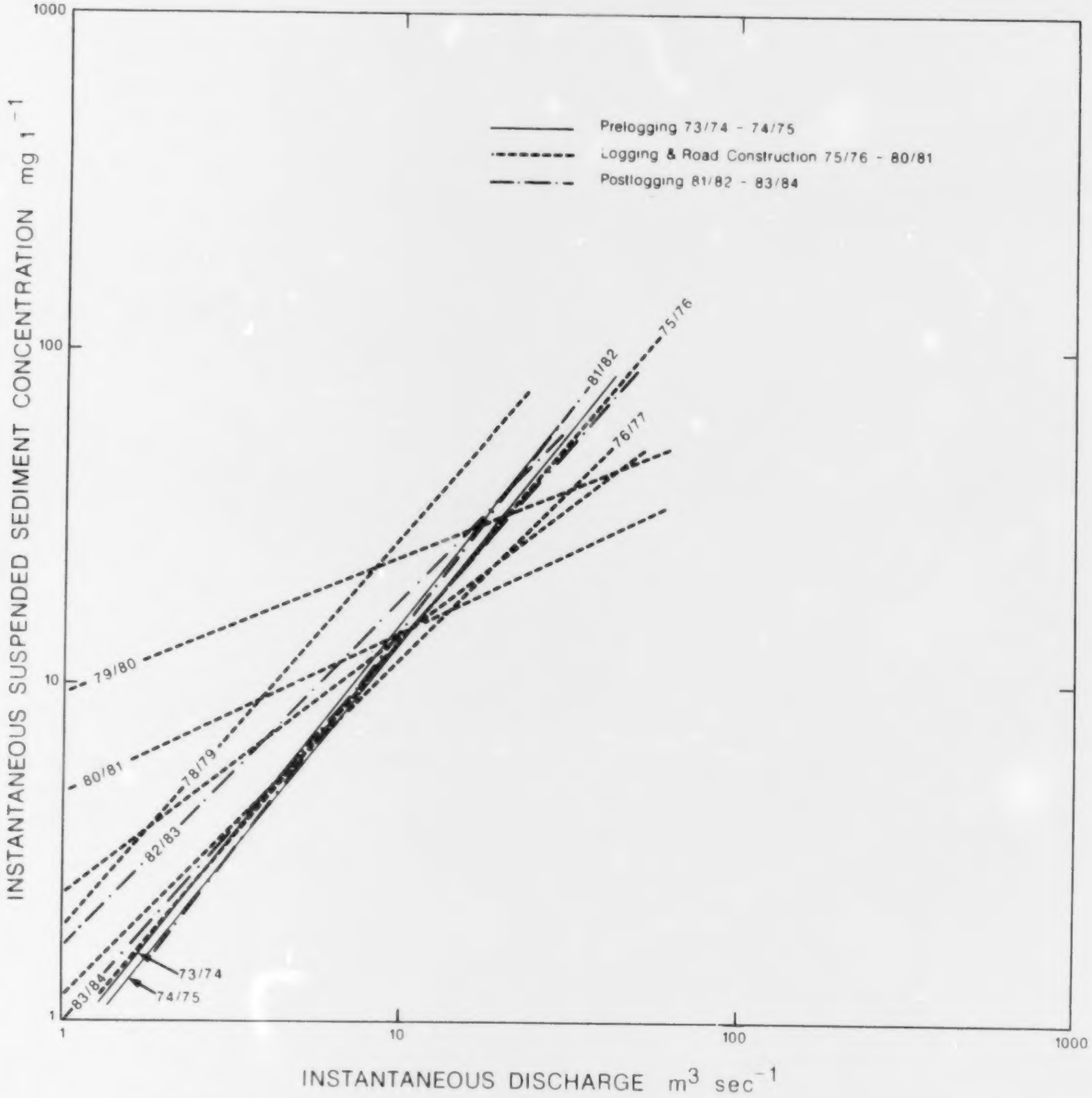

Figure 6. Carnation Creek at the mouth. Falling stage rating curves.

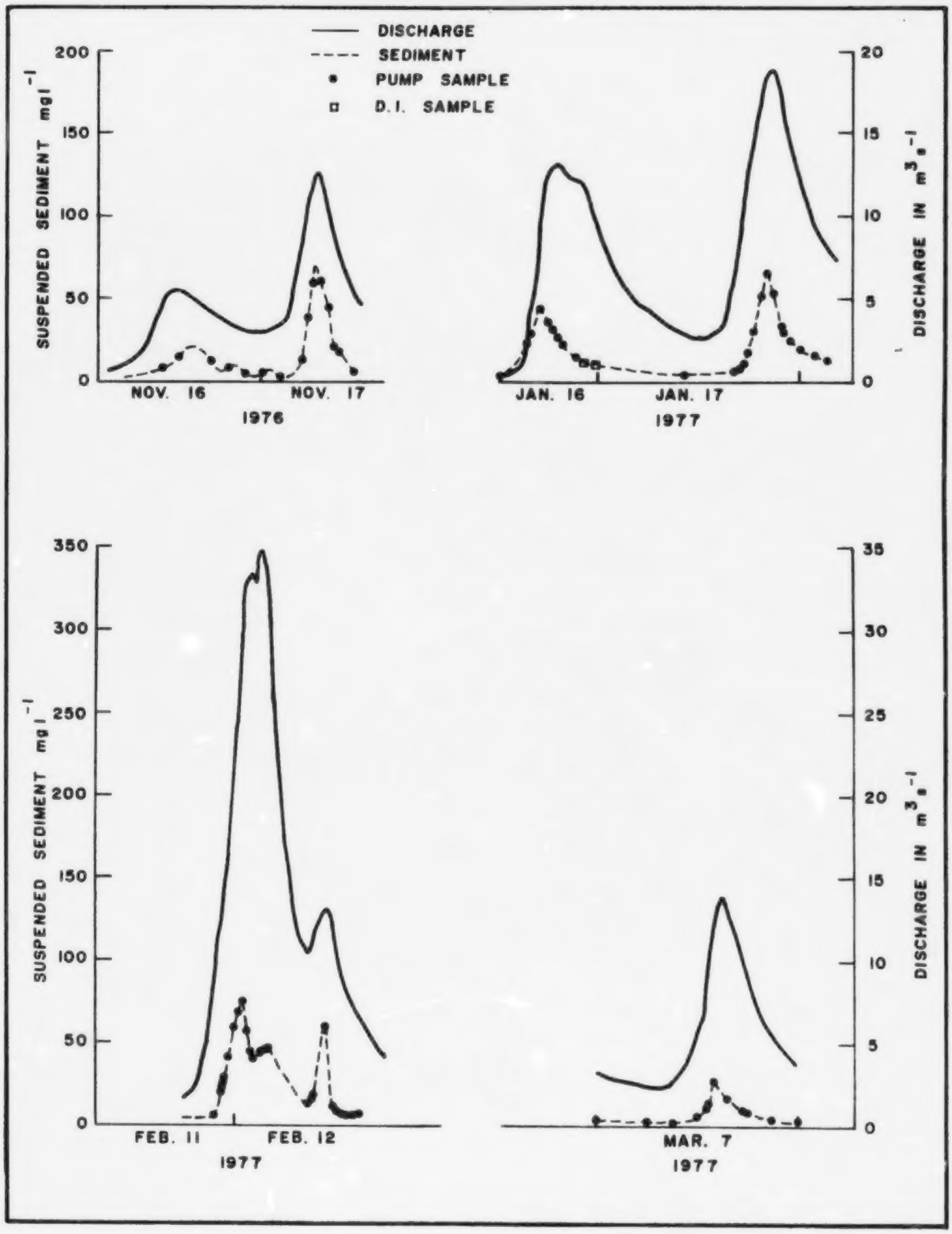

Figure 7. Carnation Creek at the mouth. Hydrographs.

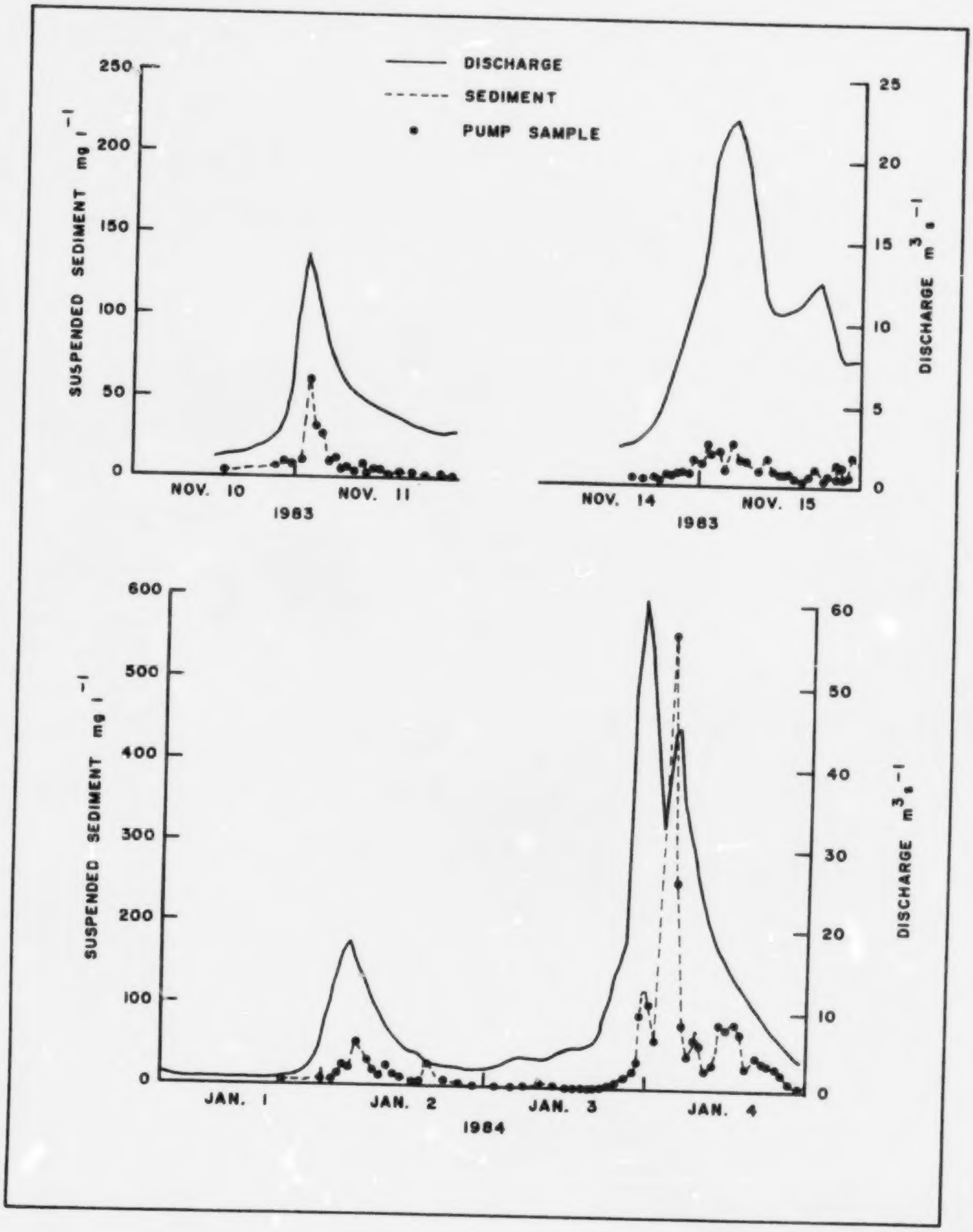

Figure 8. Carnation Creek at the mouth. Hydrographs.

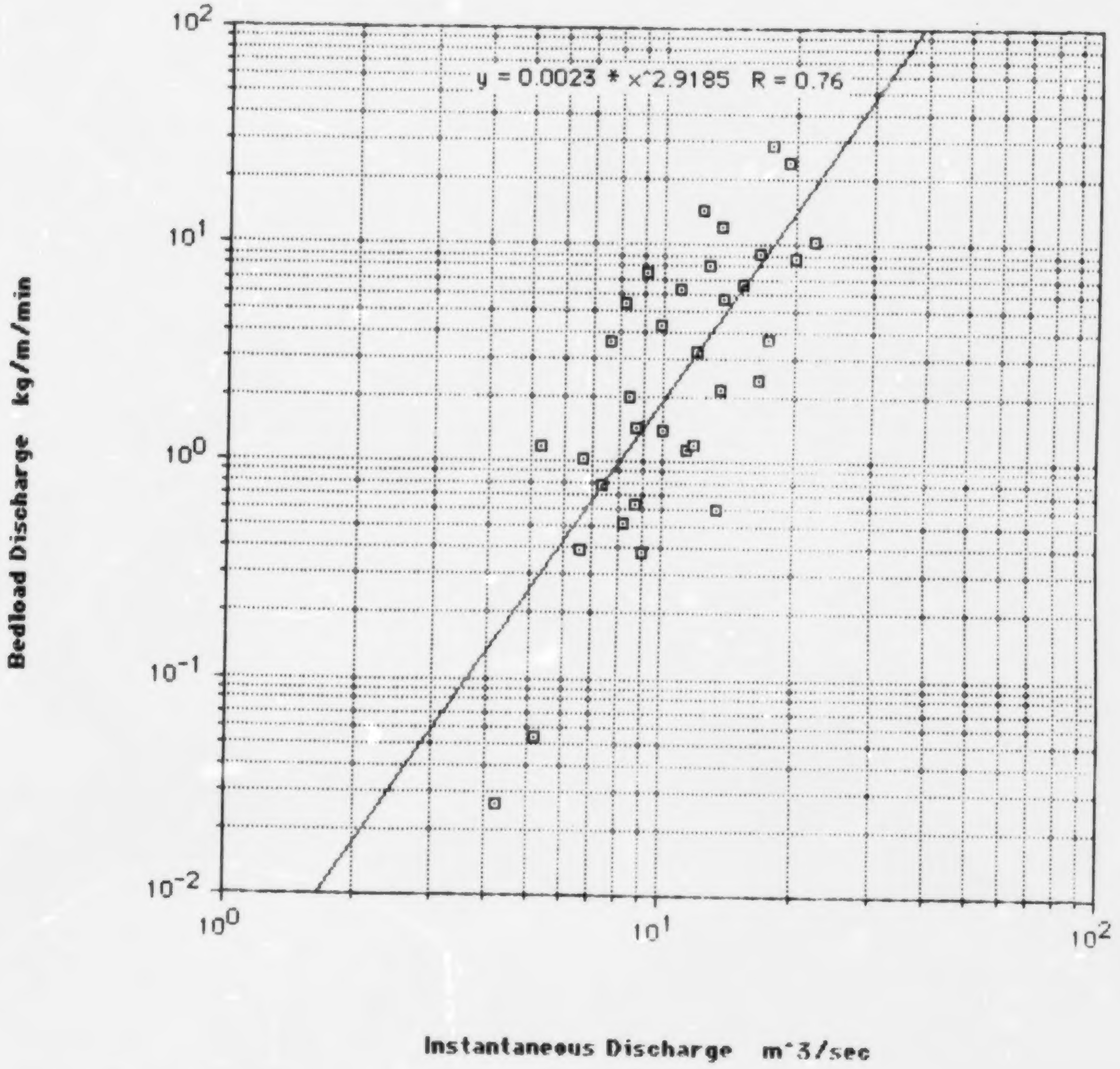

Figure 9. Carnation Creek bedload. Rising stage.

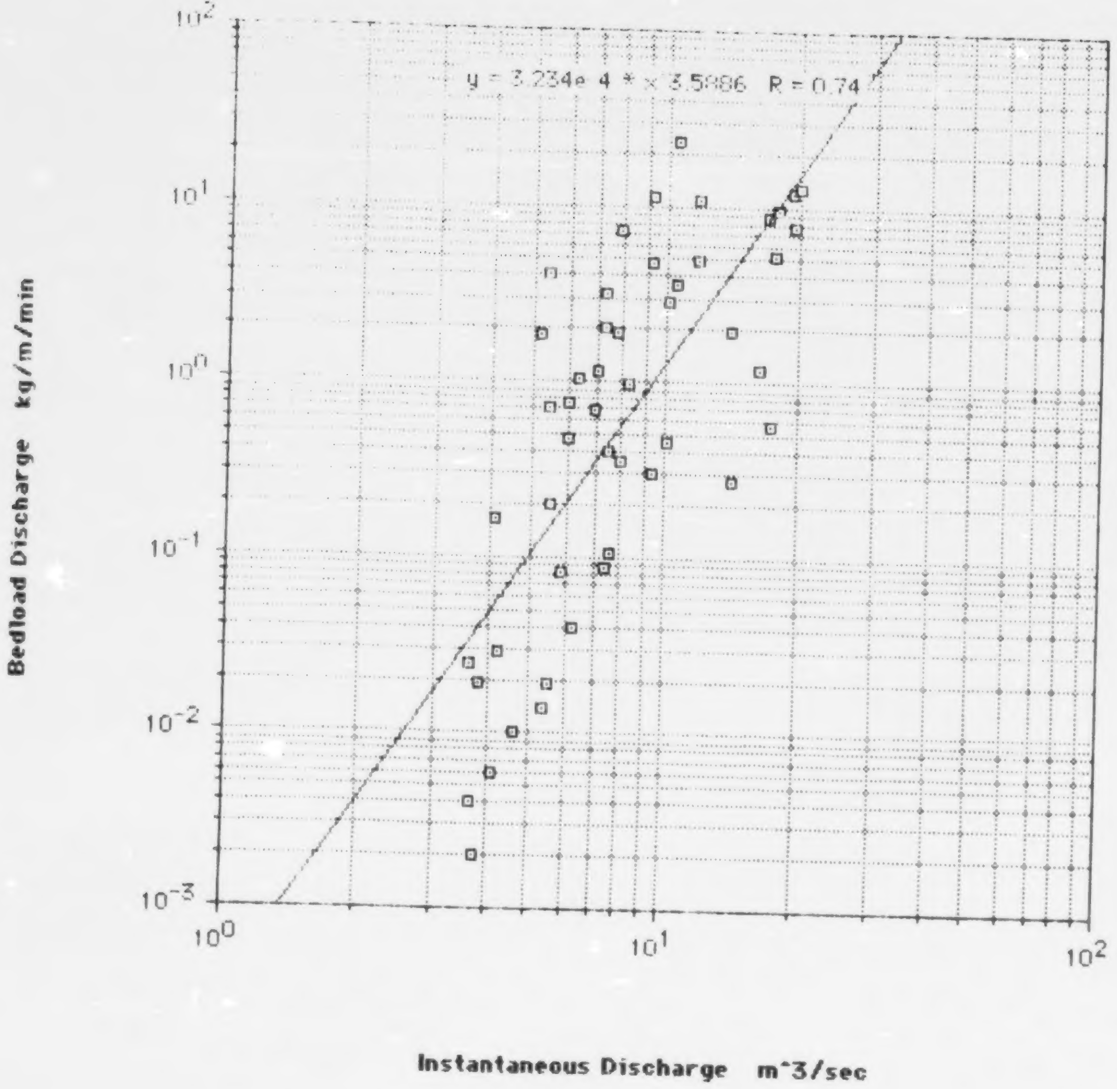

Figure 10. Carnation Creek bedload. Falling stage.

CHANGES IN COMPOSITION OF THE STREAMBED BETWEEN 1973 AND 1985 AND THE IMPACTS ON SALMONIDS IN CARNATION CREEK

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The immediate objectives of the gravel-quality programs at Carnation Creek are to assess the effects of current forest harvesting practices on the composition and quality of spawning gravel and their influence on the survival or condition of emerging fry. Changes and sources of sediment production are also being investigated. This 13 year data series (1973-85) can provide information on the rates of sedimentation and erosion of different particle sizes in the streambed. Data are available from upstream of the counting fence and from the area of intense chum spawning in the estuary.

RESULTS AND DISCUSSION

Changes in Gravel Composition

Since 1976, pea gravel (9.55-2.38 mm) and sand (2.38-0.074 mm) have increased 4.6% and 5.8%, respectively, in total composition of the streambed within or below the area of intense streamside logging (Scrivener and Brownlee, in press). Fines have also increased in the deeper layers of the streambed (Fig. 1). The patterns and rates of change in its composition were different for top (1-15 cm) and bottom (15-30 cm) layers. Rates of change and turnover were much greater in the top layer (Fig. 1). Both accumulation and cleaning of fines was detected first in the top layer. These results indicate that sudden pulses of fines entering a stream would tend to be deposited, and then cleaned away within a few years provided the system was not overloaded with sediment and provided that erosion sources healed. After a few years, when source areas of sediment became chronic and fines intruded deeper in the bed, prospects diminished for a rapid return to prelogging conditions. Net changes were similar for both layers because fines tended to accumulate at a low rate and not clean from the bottom layer, while they deposited more rapidly and cleaned partially in the top layer.

The rate of change of particles in the streambed is a function of particle size and depth. Net change and mean rates of change, as a proportion of a particle size's percentage composition, were greater for the smaller particle sizes (Fig. 1). For example, in the top layer 11.0% of the pea gravel turned over annually (mean rate 1.89% yr^{-1} /16.4% pea gravel in 1973-76; Fig. 1) compared with 47% of fine sand (mean rate 0.25% yr^{-1} /0.53% fine sand in 1973-76). Silt and clay size particles were an exception (Fig. 1). Here rate of change was so rapid that only small annual net changes were observed. Seasonal sampling of estuary spawning gravel has shown that silt and clay particles accumulated during the summer and were eroded away during the winter (Scrivener and Brownlee 1982). The smaller the particle size the greater the potential for its annual change in percentage composition.

Similar changes have occurred in the area of intense chum spawning, but here the gravel cores were split into top (0-10 cm), middle (10-20 cm) and bottom (20-30 cm) layers. Fines increased with depth, but the magnitude of change tended to decrease with depth in the streambed (Fig. 2 and 3). Fines were cleaned from the top layer, but this rarely occurred in the

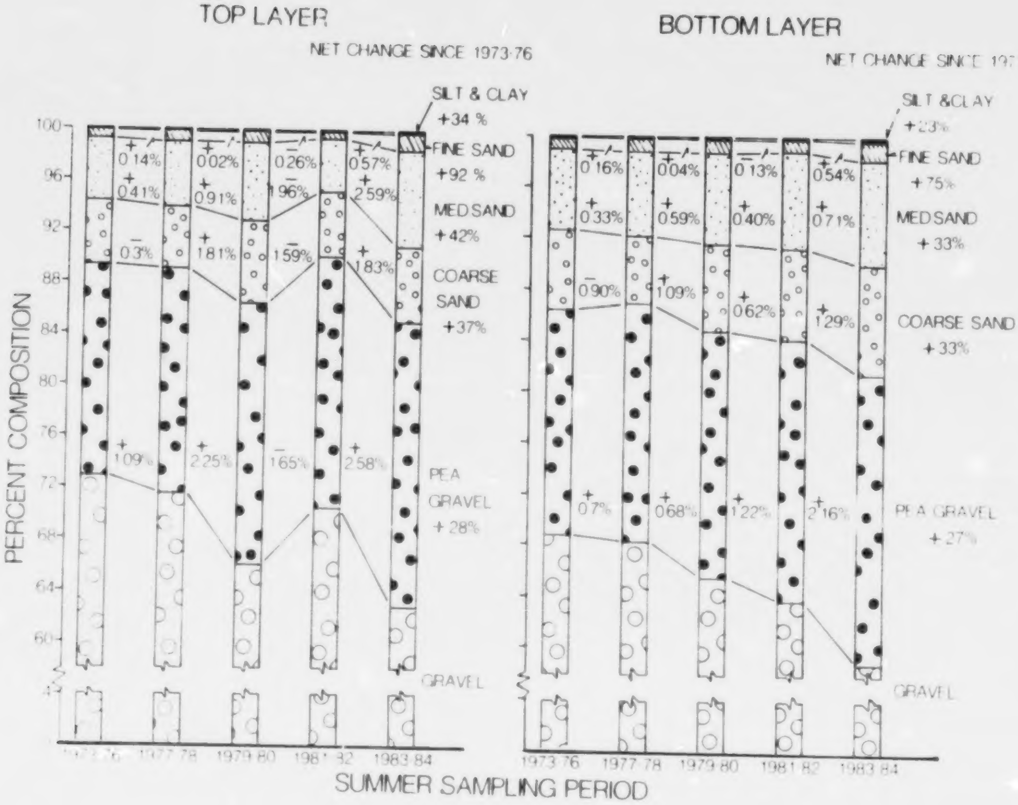

Figure 1. Percentage composition, rate of change, and net change since 1973-76 of pea gravel, coarse sand, medium sand, fine sand and silt/clay in the top and bottom layers of gravel cores from Carnation Creek.

middle or bottom layers. In this area, fines began declining in the top layer 1 year later than observed in upstream samples. This is typical of the spatial variability observed in streams (Adams and Beschta 1980). It also indicated that sediments tend to move downstream in waves (Everest et al. 1987). Eight years after the intense streamside logging, changes in gravel composition were still accelerating.

Impacts on Incubating Eggs and Fry

Two conditions contributed to decreased egg to fry survival in the post-logging period. Egg to fry mortality increased as accumulating pea gravel and sand reduced the mean particle size (Dg) of materials in the streambed (Fig. 4). Pre-emergence mortality of coho was also correlated with the magnitude of severe freshets (Holtby and Healey 1986; Scrivener and Brownlee, in press). The size of emerging chum and coho salmon were positively correlated with gravel quality (Scrivener 1987; Scrivener and Brownlee, in press), suggesting also that reduced pore size in the gravel contributed to a greater mortality among large alevins. Fry size on emergence of coho and on emigration of chum salmon has an important influence on survival (Chapman 1966; Healey 1982). Coho salmon compensated for these negative impacts when their growing season was lengthened, because emergence was earlier; and when their growth rates increased, because of lower densities during the summer (Hartman et al. 1984).

Sources of Sediment and Mode of Transport

In watersheds with forest harvesting, three major sources of sediment are from landslides or debris

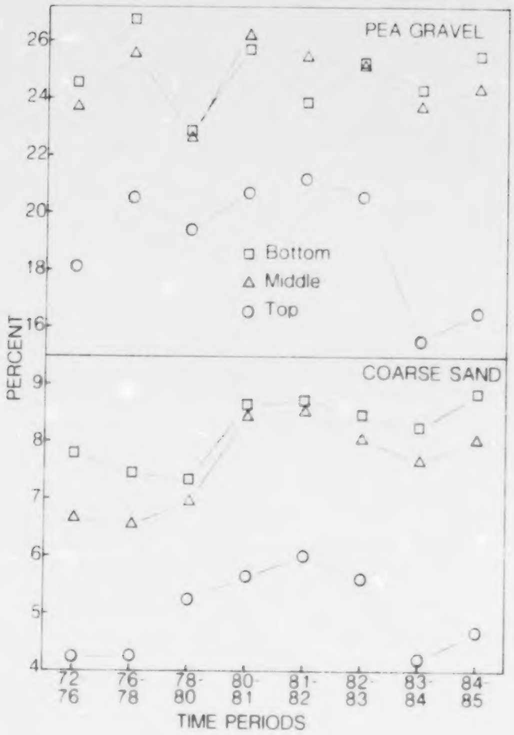

Figure 2. Composition of pea gravel and coarse sand in the streambed of Carnation Creek estuary. After logging was begun, time periods indicated egg incubation years (September to March).

torrents (Everest et al. 1987; Poulin 1986), from surface erosion on logging roads (Beschta 1978; Cederholm et al. 1981), and from upstream storage or from erosion of the stream banks (Anderson 1971; Hartman et al. 1987).

Since logging was begun in 1976/77, five landslides and three debris torrents in steep valley wall tributaries have occurred in Carnation Creek watershed (Scrivener and Brownlee, in press). The areas involved were small and some sediment from only one of the debris torrents was deposited in the main channel. Most of the material was deposited on roads, on lower valley slopes, or on the valley floor (Hartman et al. 1987). Therefore, these sources probably contributed little to the changes in the quality of spawning gravel.

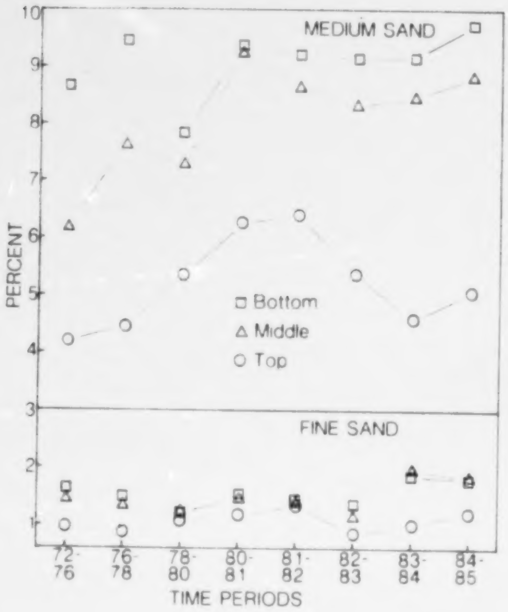

Figure 3. Composition of medium and fine sands in the streambed of Carnation Creek estuary. After logging was begun, time was the period of egg incubation (September to March).

Road surfaces can be a major source of sediment. In the Clearwater River basin, fine sediments that washed off roads equalled that produced by landslides (Cederholm et al. 1981). Particles smaller than 0.85 mm in diameter in the streambed were correlated with area of roads in the watershed. At Carnation Creek, roads were constructed from blast rock and surfaced with hard and coarse gravel, so few fine particles were eroded and heavy truck traffic would fragment little of this surfacing material (Ottens and Rudd 1977). Since most roads were located well away from the stream, since most of the sediment affecting quality of spawning gravel were medium sands or larger, and since sediments washed from road surfaces are usually finer (Beschta 1978; Cederholm et al. 1981); roads were probably not a major source of sediment that accumulated in the stream.

In Carnation Creek, much of the sediment affecting quality of spawning gravel probably came from eroding stream banks or from channel storage upstream. The loss of large "roughness elements" such as logs and root wades have greatly reduced channel stability (Toews and Moore 1982; Everest et al. 1987; Hartman et al. 1987). In the areas of intensive and careful streamside treatment, bank erosion increased 2.7 times since logging was begun

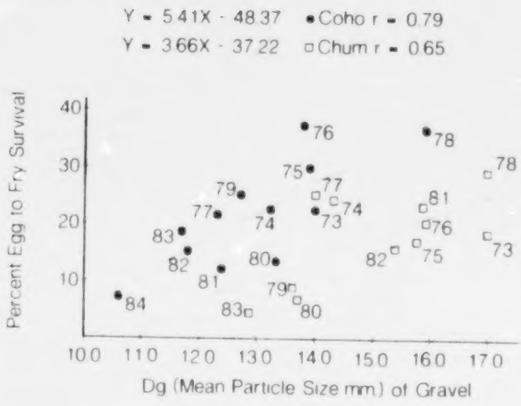

Figure 4. Relationships between annual egg-to-fry survival of coho and chum salmon and mean particle size in the bottom and top layers, respectively of gravel cores from the undisturbed and intensive treatment areas.

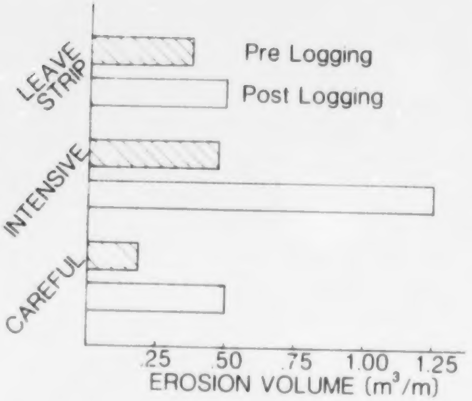

Figure 5. Streambank erosion increases in the undisturbed, intensive, and careful streamside treatments in Carnation Creek. Changes are compared for three prelogging and postlogging years.

(Fig. 5). A slight increase occurred in the leave strip treatment. During a January 1984 freshet, loss of a debris and gravel wedge in the canyon released a torrent which deposited in the careful treatment area. New sediment was deposited to a maximum depth of 1.5 m in this area. These sediments were now available for transport in the areas used by spawning salmon and trout.

Two modes of sediment transport are often described for streams: 1. suspended transport of fine particles which are maintained in suspension by the turbulence of flowing water; and 2. bedload transport of coarser particles which roll, slide, or saltate downstream in close proximity to the bed. The transport of suspended particles can occur during most flow conditions, because the hydraulic forces required to keep these particles in suspension are relatively low once they become entrained. When suspended sediment infiltrates the streambed it fills the pores of the gravel from the bottom up, leaving the upper layers relatively clean (Einstein 1968). The size of particles in suspension increases as flows increase. This was a major mode of sediment transport and sedimentation which led to reduced quality of spawning gravels in the Alsea, Oregon (Fig. 6) and Clearwater, Washington basins (Beschta 1978; Adams and Beschta 1980; Cederholm et al. 1981). The impacts can occur quite quickly (<1 year). Conversely spawning gravels can be cleaned of these fines just as quickly (Adams and Beschta 1980). This material often originates from the surface of logging roads. In Carnation Creek, yields of suspended sediment were low and changed little during road construction or during logging (Fig. 7). Annual yields were 40% to 200% of prelogging values and 10% to 40% of postlogging values that were observed during the Alsea watershed study (Fig. 6 and 7).

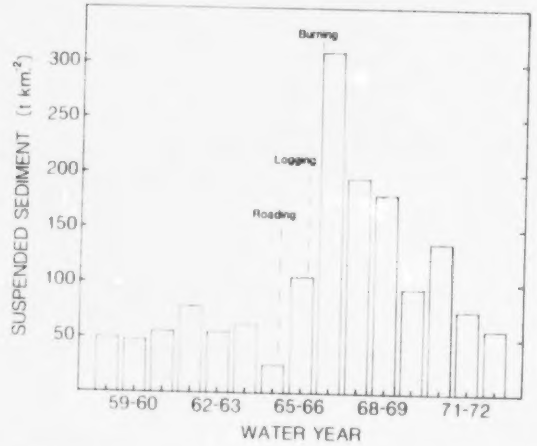

Figure 6. Increases in annual suspended sediment yield after road building and 82% clear-cut logging on Needle Branch, Alsea watershed, Oregon, redrawn with permission of R.L. Beschta (19 78).

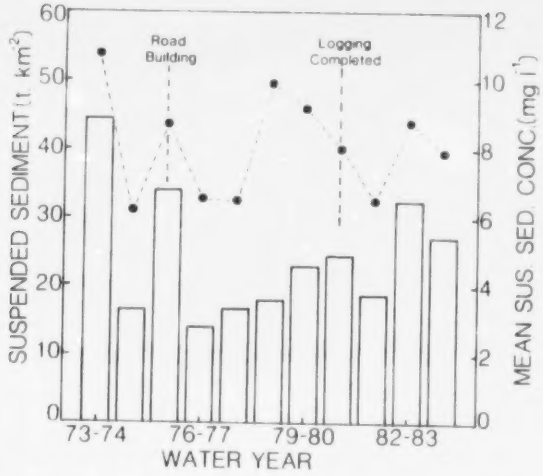

Figure 7. Suspended sediment yield and mean concentration by water year (October to September) observed at B weir in Carnation Creek watershed.

The major mode of sedimentation in Carnation Creek is by bedload transport. As particles saltate downstream during freshets, they become trapped in the voids on the surface of the substrate and this forms a barrier to further intrusion (Beschta and Jackson 1979). As flows increase the size of particles, the distance they move, and the depth of scour also increase. Now, sand particles become trapped a few cm. below the depth to which scour occurs during the freshet (Beschta and Jackson 1979). Therefore sedimentation occurs from the top down in the streambed and the composition of deeper layers is unchanged until a freshet occurs that is large enough to cause extensive scouring. As a basin is exposed to larger freshets with longer return periods, the depth to which sand seals are formed becomes greater. Cleaning of the streambed occurs in the same manner. The larger the fine particles and the deeper their penetration, the slower their rate of cleaning. Data from Carnation Creek show this pattern of sedimentation and erosion. Changes in gravel composition were dependent on frequency of peak flows, on spatial relations to streamside treatments (source of sediment) and on timing of logging activities (Scrivener and Brownlee, in press). When new sources of sediment decline, cleaning of spawning gravels will also depend on the frequency of large freshets. Pea gravel and sands are still accumulating in the deeper layers, 9 years after logging was begun.

MANAGEMENT IMPLICATIONS

Resource managers must understand these fluvial processes in a watershed in order to develop the best forest harvesting plan for it. Increased mortality among incubating salmon eggs was reported during the Clearwater (Cederholm et al. 1981; Tagart 1984) and Carnation Creek (Scrivener and Brownlee, in press) watershed studies. This was also implied for the Alsea watershed and Queen Charlotte Island studies, when the quality of spawning gravel declined (Moring 1975; Poulin 1986), but the size of offending particles in the streambed, their mode of transport and sedimentation and their source areas varied among the studies as discussed earlier. Therefore, the required management prescriptions to reduce these mortalities would have to be different.

Time frames of impacts must also be understood by managers if the best resource options are to be chosen. For example, short term impacts from sedimentation of silt and clay size particles might be more tolerable than longer term sedimentation of larger particles. The magnitude of possible impacts can also effect the time frame of the impact. When the length of sediment impacts increase the probability of natural regulators occurring also increase. Naturally occurring events such as floods in the stream or el Nino processes in the ocean can act synergistically with these man induced impacts to severely effect the resilience of a salmon stock (Cederholm et al. 1981; Holtby, 1988).

ACKNOWLEDGMENTS

This long term program was only possible because of contributions from a large number of people. The technical contributions of J. Arseneault, A. von Finster, R. Laird, J. Lamb, and R. Leahy require special acknowledgment. The editorial or advisory assistance of Drs. G. F. Hartman and L. B. Holtby were gratefully accepted.

REFERENCES

Adams, J. N. and R. L. Beschta. 1980. Gravel bed composition in Oregon coastal streams. Can. J. Fish. Aquat. Sci. 37: 1514-1521.

Anderson, H. W. 1971. Relative contributions of sediment from source areas, and transport processes, p.55-63. In: J. T. Krygier and J. D. Hall [Eds.]. Proceedings of a symposium

Forest Land Uses and Stream Production. Oregon State Univ., Corvallis, OR. 252 p.

Beschta, R. L. 1978. Long-term patterns of sediment production following road construction and logging in the Oregon coast range. Water Resour. Res. 14: 1011-1016.

Beschta, R. L. and W. L. Jackson. 1979. The intrusion of fine sediments into a stable gravel bed. J. Fish. Res. Board Can. 36: 204-210.

Chapman, D. W. 1966. Food and space as regulators of salmonid populations in streams. Am. Nat. 100: 345-357.

Cederholm, C. J., L. M. Reid, and E. O. Salo. 1981. Cumulative effects of logging road sediment on salmonid populations in the Clearwater river, Jefferson County, Washington, p.38-74. In: Proceedings from the Conference Salmon-Spawning Gravel: A Renewable Resource in the Pacific Northwest? Wat. Res. Cen., Wash. State Univ., Pullman, WA. 285 p.

Einstein, H. A. 1968. Deposition of suspended particles in a gravel bed. J. Hydraulics Div. ASCE. 94(HY5): 1197-1205.

Everest, F. H., R. L. Beschta, J. C. Scrivener, K V. Koski, J. R. Sedell, and C. J. Cederholm. 1987. Fine sediment and salmonid production: a paradox, p.98-142 In: E. O. Salo and T. W. Cundy [Eds.]. Streamside Management: Forestry and fishery interactions. College of Forest Resources, AR-10, University of Washington, Seattle, WA. 471 p.

Hartman, G. F., L. B. Holtby, and J. C. Scrivener. 1984. Some effects of natural and logging-related winter temperature changes on the early life history of coho salmon in Carnation Creek, p.141-149. In: W. R. Meehan, T. R. Merrell Jr., and T. A. Hanley [Eds.]. Proceedings of a symposium, Fish and wildlife relationships in old-growth forests. Am. Inst. Fish. Res. Biol. available from J. W. Reintjes. Rt. 4, Box 85, Morehead City, NC 28557. 425p.

Hartman, G. F., J. C. Scrivener, L. B. Holtby, and L. Powell. 1987. Some effects of different streamside treatments on physical conditions and fish population processes in Carnation Creek, a coastal rain-forest stream in British Columbia, p.330-371. In: E. O. Salo and T. W. Cundy [Eds.]. Streamside Management: Forestry and fishery interactions. College of Forest Resources, AR-10, University of Washington, Seattle, WA. 471 p.

Healey, M. C. 1982. Timing and relative intensity of size-selective mortality of juvenile chum salmon (*Oncorhynchus keta*) during early sea life. Can. J. Fish. Aquat. Sci. 39: 952-957.

Holtby, L. B. 1988. Effects of logging on stream temperatures in Carnation Creek, British Columbia, and associated impacts on the coho salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 45(3).

Holtby, L. B. and M. C. Healey. 1986. Selection for adult size in female coho salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 43: 1946-1959.

Moring, J. R. 1975. The Alsea Watershed Study: Effects of logging on the aquatic resources of three headwater streams of the Alsea river, Oregon. Part III - Discussion and Recommendations. Fish. Res. Rep. 9, Oregon Dept. Fish. Wildl., Corvallis, Oregon. 24 p.

Ottens, J. and J. Rudd. 1977. Environmental protection costs in logging road design and construction to prevent increased sedimentation in the Carnation Creek watershed. Rep. BC-X-155. Can. For. Ser., Pacific Forest Research Centre, Victoria, British Columbia. 28 p.

Poulin, V. A. 1986. Fish/Forestry Interaction Program: Summary-Part 1. Extent and severity of mass wasting on the Queen Charlotte Islands and impacts on fish habitat and forest sites. V.A. Poulin & Associates Ltd., Vancouver, British Columbia. 23 p

Scrivener, J. C. 1987. A summary of the population responses of chum salmon to logging in Carnation Creek, British Columbia between 1970 and 1986. In these proceedings.

Scrivener, J. C. and M. J. Brownlee. 1982. An analysis of Carnation Creek gravel-quality data, 1973-1981, p. 154-176. In: G. F. Hartman [Ed.]. Proceedings of the Carnation Creek workshop, a 10-year review. Pacific

Biological Station, Nanaimo, British Columbia. 404 p.

Scrivener, J. C. and M. J. Brownlee. in press. Effects of forest harvesting on spawning gravel quality and on incubation survival of chum (*Oncorhynchus keta*) and coho salmon (*O. kisutch*) in Carnation Creek, British Columbia. Submitted to Can. J. Fish. Aquat. Sci.

Tagart, J. V. 1984. Coho salmon survival from egg deposition to fry emergence, p.173-181. In: J. M. Walton and D. B. Houston [Eds.]. Proceedings of the Olympic Wild Fish Conference, March 23-25, 1983. Fisheries Technology Program, Peninsula College, Port Angeles, Washington. 308 p.

Toews, D. A. and M. K. Moore. 1982. The effects of three streamside logging treatments on organic debris and channel morphology of Carnation Creek, p.129-153. In: G. F. Hartman [Ed.]. Proceedings of the Carnation Creek Workshop, a 10-year review. Pacific Biological Station, Nanaimo, British Columbia. 404 p.

PANEL DISCUSSION
SESSION 2: SEDIMENT AND GRAVEL

RESPONSE BY RON JORDENS, FIELD ENGINEER, MINISTRY OF FORESTS AND LANDS

Bruno Tassone's paper "Sediment Loads from 1973 to 1984" found that:

a. The majority of the sediment load is transported between October and March, which coincides with the high discharge months in the watershed.

b. The amount of load (bed and suspended) per year remained the same regardless of the activity within the watershed.

c. Increased storm flow normally increases sediment production.

d. Sediment concentration decreases with each successive storm providing peak flows do not exceed the previous one (i.e. Carnation Creek is sediment supply limited).

e. Bedload comprises at least one half of the total load.

Charles Scrivener's paper "Changes in Composition of the Streambed between 1973 and 1985 and the Impacts on Salmonids in Carnation Creek" found that:

a. The percentage of pea gravel, coarse, medium and fine sands all increased at the test site during the study period. High percentages of these grain sizes can be detrimental to egg and fry survival.

b. Erosion in Carnation creekbed in the various test sections all increased.

c. Egg to fry survival rates for coho and chum decreased as particle size in the bottom and top layers of the creek channel decreased.

d. Changes in gravel composition are dependent on peak flows, sources and type of sediment and on timing of logging activities.

e. It appears that the egg to fry survival rates have been reduced significantly due to sedimentation; the sources of sediment are not from road and general logging activities, but from streambank erosion, upstream channel storage; and streambank disturbance caused by removal of logs felled across the stream.

1. Comments on the findings from a Forest Service Engineering veiwpoint

    a. The findings and results are not new but reinforce what was already known or suspected (i.e. dirt, water and fish do not mix well).

    b. It should be noted that without soil we have reduced the capacity to maintain a renewable forest.

    c. So by minimizing erosion we serve the fish and forestry resources well.

Point of Confusion

Charles' paper indicated that roads were likely not a major source of sediment within Carnation Creek. I got the impression from Eugene that he felt differently. Can this be clarified?

2. Applicability of the Results?

   a. These studies deal with the Carnation Creek drainage. We need to know if the results and processes are applicable to other drainages.

   b. If so which one (specifically or generally).

3. What should we be doing with the data to improve forestry and fisheries practices?

   a. Information, theories, hypotheses and processes identified from the studies should be summarized and be readily available in "lay-man" language and should be mandatory reading for everyone that works in our forests. (The individual research papers can be made available in the normal fashion for those who are interested in more detail.)

   b. The more forest workers understand the effects they may have on natural processes of what they do the better the chance of minimizing the impact.

4. Some things that can be done to minimize erosion/sedimentation:

   a. It must be accepted by all that erosion/sedimentation cannot be 100% prevented.

   b. To minimize logging impact on the Fishery Resource we must:

      i. Idenfity sources of sedimentation that are likely to reach fish bearing waters. In some areas of the Regions and with some of our tenures this is being done through soil-terrain mapping, slope stability hazard maps, reports by soil specialists, etc. In other areas and/or tenures there is more to do in this area.

      ii. Once a problem is identified it's impact requires assessment and a solution agreed upon.

Hopefully we are always "asking" and "answering" the question "Is the cost of the solution worth it"?

a. Are we asking people to do things that are impractical and costly? Have we asked those who will do the work for their input? Are we being reasonable and practical?

b. If the alternate more expensive logging or road constraint is recommended, who is going to pay the extra cost and do they know it and have they agreed to it. i.e. an agency asks a Licensee to do something and everyone expects the Forest Service to pay; or the Forest Service asks the Licencee to do something the cost of which is not in the appraisal?

Once the problem is identified the solution and cost agreed upon and the cutting or road permit issued nicely covering the contentious issues, the work begins:

i. Are the field supervisors, operators, contractors, R.A.'s etc. aware of the problem areas? - make sure they are!

With soil - water problems most events are irreversible.

c. After they happen very little can be done to rectify the damage and it is normally more expensive; and everybody is ticked-off.

d. Sometimes river gravels are the only cost effective source of road ballast and/or surfacing materials available. The studies indicate that some depositions are harmful to egg/fry survival and perhaps removal of this material could benefit all? Rock ballast costs about $4 per cubic meter more to produce than gravel. Savings can be $10,000 per km for every 0.5 m of ballast required which could end-up in the public coffers available for other public programs.

Conclusion

a. We must know how our actions impact on other resources.

b. We must work together in a cooperative spirit to solve multi-resource conflicts in the most cost-effective manner.

c. We must have:

- good resource information
- good planning
- good contracts
- good contract supervision
- well informed and supervised field people
- appropriate logging and road construction and maintenance practices
- appropriate rehabilitation measures (i.e. putting roads to bed, and other erosion prevention procedures)

Parting Thoughts

a. If today's more stringent logging and road constraints (i.e. no intensive strip) were applied to Carnation Creek would there be fisheries concerns?

b. Monitoring of egg-to-fry survival should be continued to see if the survival rates return to pre-logging values.

c. Perhaps some stream bank erosion control in the intensive strip should be undertaken.

RESPONSE BY DICK KOSIK,
C.I.P. INC.

Ron Jordens has considered the practical applications of both presentations whereas I will question the results primarily for my own clarification and for stimulating discussion.

The papers are highly technical, are complete with equations, tables, and graphs. For inhouse exchange of data amongst hydrologists they are excellent. From practicing foresters point of view I must admit portions of the papers are difficult to comprehend. The information should be presented in laymans terms so that every forester, engineer, technician and supervisor can understand the purpose of the research and understand the results.

Bruno states that apparent peak flows were much lower prior to 1975/76 watr year i.e. prior to logging. Water years 77/78 and 80/81 were respectively $2 m^2$/sec. and $1 m^3$/sec. higher --- this is not significant. Peak flows in the 60's were perhaps higher than in the post logging period.

Although peak discharge was slightly lower in 1973/74 prior to logging the suspended sediment was the highest ever attained.

Bruno states that suspended and discharged sediments and cumulative load in Carnation Creek depict similar response patterns to that of an Oregon undisturbed stream. This suggests that logging has little effect on sediment patterns.

No reference is made of a control in Bruno Tassone's study.

Charles Scrivener states "the rate of change of particles in the streambed is a function of size and depth."

The rate of change must also be a function of flow rate, streambed condition, streambed configuration and postions in the length and cross section of the stream and frequency of freshets and amount of large organic debris.

Precipitation variation, unusual weather patterns, natural slides, blowdown along stream banks are not mentioned and they all could be as much of a factor to gravel composition changes as the so called "intense logging activity".

Charles notes that "In watersheds with harvesting, three major sources of sediment are:

- from landslides an debris torrents
- from surface erosion on logging roads
- from upstream storage or from erosion of stream banks

Not all watersheds have landslides or debris torrents.

Since logging started in 1976/77 5 landslides and 3 debris torrents occurred, it doesn't say whether these were a result of harvesting or natural causes.

It is stated that slides and road construction and road surfaces contributed little to stream sediment. This message is quite different to what we heard yesterday. Eroding stream banks and upstream channel storage were the main contributors of stream sediment. Therefore one can assume logging has little influence on the production of fines which affect gravel quality adversely. The author notes sand particles tend to form a barrier to "further intrusion" suggesting shallow penetration of sedimentation from the top down. Then he states the larger the fine particles the deeper the penetration; which is correct?

In Table I [Tassone's paper] there is an illustration of erosion volumes based on degree of activity but we must remember there is a substantial time element involved here. In a mature and overmature forest there are dynamic changes in the stream along the shores and in the upper slopes. What percent did this contribute to the increase in erosion volume? The author successfully demonstrates changes in streambed composition but I'm not convinced these changes occurred throughout the stream and further he convinced me they were not entirely the result of logging activity. No mention is made of a control in this study either.

RESPONSE BY NORM LEMON,
DEPT. OF FISHERIES AND OCEANS

I have looked at these papers from a Fisheries Manager point of view. I have been working in most of the Coastal Forest Regions in the last 18 years, and am held accountable by all the users of fish in these areas for the fish they did not catch. As a Fishery Officer I have had a great many occassions to prosecute commercial and recreational fishermen for activities that result in collection overharvesting. Without exception each individual made the statement that he was not to blame for reduction in productivity - it was all due to poor logging practices!! Similar statements are made at every DFO meeting with various fishermen groups. Every logger talks about overharvesting the fishery. You are all aware that DFO has a new policy for management of Fish Habitat. On introduction of the policy our Minster stated that this policy is "an explicit recognition by Canada that fish habitat are important national assets". He further stated that our department "will work cooperatively towards the objective of net gain of fish habitat through integrated resource planning, that is to reconcile the interests of the many sectors which compete to the use of habitat area."

Society demands hard, objective information to resolve these problems.

How can I as a Fisheries manager apply this hard, objective information to the objective of net gain through reconcilation of the interests of Forest Harvesting and Fisheries Production?

There have been several comments about fish production from Carnation Creek. We are presently running the salmon resource at 50% (or less) of wild production capacity. Bring it up to full capacity - add enhancement and Ocean Farming and we have a multi billion dollar business in British Columbia instead of a multi million dollar business. Streams like Carnation Creek are the production areas.

These reports confirm logging has an impact on Salmonid production through increases in sediment and changes to gravel composition. They formally identify the magnitude of the complexity of running both Forestry and Fisheries at 100%.

Charles Scrivener found the "Eight years after intense streamside logging, changes in gravel compostion were still acelerating."

Also, "In the areas of intensive and careful streamside treatment bank erosion increased 2.7 times since logging was begun. A slight increase occurred in the leave strip treatment."

I can use these examples to indicate how this research can nail down problems and identify answers.

Summary

These reports describe to me the complexity of logging and fisheries relationship. They also provide some direction for site specific problems that can be used in planning and operational phases. We must not rationalize the results of the research - we must apply it. I am looking forward to Thursday's session on integrating and applying 15 year's results.

QUESTIONS
SESSION 2: SEDIMENT AND GRAVEL

Moderator: R. Morley

MR. HOGAN: Dan Hogan. Yes, I'm wondering if I could open the door to ask less detailed questions? I thought I'd take a shot here.

Charles Scrivener said that the main source of sediment was from in-channel sources. My question is what is the effect of four weirs in the channel?

First off, it seems to me that there are at least two or three weirs on the stream that would trap sediment from coming downstream, and the downstream weir would have upstream effects by aggradation which would lead to finding sediment. Can you clarify the influence of weirs on sediment transport and storage?

MR. SCRIVENER: Well, they certainly do a lovely job of catching sediment. Of the samples, the cores that I've used here, there is only one section of the upstream samples that was actually below "B" weir. The rest of them were above "B" weir. There are only two weirs on the main stem, the rest of them are on tributaries, and the other one on the main stem is an unlogged tributary.

Essentially "B" weir is about here, and other than one section here all of the other samples were taken above it. There's a weir here on "C" watershed. There was not very much in the way of cleaning over the whole fifteen years done in that particular system.

The other watershed, the other weir on the main stem, is way up here again on a controlled watershed ("E"). The others are very tiny as to total area.

So most of the samples that I was talking about upstream are a long way from any weir influence.

MR. HOGAN: I guess the question is the downstream weir appeared to be about a meter or so; what it reminded me of was Les Powell's discussion of the influence behind that big log jam. So that would lead to a lot of more fine sediment upstream, or is it far enough upstream not to influence the quality?

MR. SCRIVENER: That little step filled in on the first freshet way back in 1971. The amount of material transported in that system is so great that a section like "B" weir is cleaned out sometimes two and three times a year. There's so much material that comes down.

So the amount of material moving as bedload will totally swamp any small structure you put in the system.

MR. SCHULER: Mark Schuler. I'm with the Washington State Department of Fisheries, and I work in an area just south of the border where we have many of these problems already happening to the extent that we don't see what we can do about them.

I think that the bedload problem has really been looked at as a special problem in some of the talks yesterday, and Mr. Scrivener's today, I think, was one of the better ones on this bedload problem.

One of the talks yesterday said that the peak flows in tributary streams in intense logging areas did change from logging, and yet the peak flows in the main stream down channel didn't seem to change that much, and that was just let go by as well, no big deal. But each one of these peak flows that changes in these intense logging areas and streamside channels is also moving bedload.

I would agree with Mr. Scrivener that in our area in the steep drainages, our logging is twice as high as what you're talking here, and it's mainly the flatland could be considered the logging with the careful treatment.

But as soon as you get in the steep draws above salmon use, it's all intensive logging.

Our bedload problems are so tremendous we're constantly having to dredge out lower streams and whatever. I argue that the thing that was brought up yesterday by Mr. De Leeuw that channel width has increased tremendously after the storms of '82 and '84, that that is going to continue all the way down the mouth of Carnation Creek and eventually effect the entire chum spawning area just from past experience looking at it.

What I want to know is do you feel if the intensive logging, you've only got 41 percent of the watershed logged now, if that intensive logging is continued on the tributary streams and the entire watershed is logged off, do you see these problems will increase, and is there anything you can do about them once they do?

MR. SCRIVENER: I think it's very hard to do anything with them after they have already been logged. It's got to be put into the prescription.

The basic thing I was trying to demonstrate in my presentation was purely that the source areas in this particular case are a little bit different. If you had a wider or narrower valley bottom unlike this with steep side slopes, most of the material would come from mass wasting or from the other sources. It would have entered directly in the stream, and it wouldn't have been by just purely bank erosion.

We have only seen now really about seven years post logging, and what we are seeing in the data is suggesting that hey, things are still accelerating. I would expect material that's in the intense treatment section, a lot of the material is still there from bank erosion, it is slowly going to move its way down.

If you remember the comparison I had between the estuary samples and the upstream samples, the pea gravel from those areas hasn't even got down to the estuary yet. There's a lot of things that are going to occur over the next 15 to 20 years.

DR. HETHERINGTON: I just wanted to clarify -- I think Charlie added a bit here about what Bruno Tascone had to say about the sources of sediment.

There are relatively few steep sections of road in the watershed. Most of the roads are contoured, so that although we have had subsequent erosion on those sections of road, they have not been very extensive and in most cases have not had access to a tributary stream that would carry the sediment down to the main stream; and, secondly, most of the side tributaries, both the temporary and permanent, hit the flood plain and had a very flat grade or simply disappeared into the flood plain before they reached the main channel. So those sediments are filtered out.So there's very little access from the side slopes to the main channel, and that's the reason most of the sediment is coming from within the channel.

MR. SCRIVENER: I essentially see no conflict in what I said today and what you said yesterday.

DR. HETHERINGTON: No, it was just clarifying that I don't think I made the point that the road system, "C" section, for example, weren't very extensive.

MR. SCRIVENER: We were very lucky in Carnation Creek in developing a logging plan. They had access from three or four locations into the watershed, and most of the road construction was well away from the channel.

MR. DE LEEUW: Dionys de Leeuw. Charles, how did you calculate your mean particle size, and why did you use it in your analysis of side channels for juvenile fish?

MR. SCRIVENER: Rather than, say, another index of some kind?

MR. DE LEEUW: Well, no, I'm just wondering whether you couldn't have used something like the volume of fines within a certain volume of gravel rather than percentages or mean particle size.

MR. SCRIVENER: Well, I used mean particle size because it's a nice, normal distribution. It's easy to calculate the statistic.

MR. DE LEEUW: If you get large pieces and very small pieces, in other words the variance is great, wouldn't that, in effect, affect the survival?

MR. SCRIVENER: It does a great deal, and the only way to swamp it is with lots of samples, which we have. You're dealing with hundreds of samples.

MR. HARDING: Ted Harding. Charlie, if I follow your talk, you're talking about increased sediment in the gravel caused mainly by bank instability in the intense treatment areas; hence, lower survival rates of fish due to the higher sediment levels in the gravel. I just want to throw an option to that to you.

Some of the early work done by McNeill up in Alaska, found that one of the chief causes of egg to fry mortality was, for spawning pinks, ice scour and the scour of spawning beds during the winter.

In the Charlottes, some of the work I did was interesting. We had our scour monitors in, and some of the major scouring points we got was when there was a shift of debris over top of one of our scour monitors. You may get a couple of centimeters, you may get a foot. Just "bang", it was gone. You talked about the control in the intense treatment area as having a lot of bank erosion. Les Powell reported a lot of movement of debris yesterday. My conjecture is your lower survival rates are a function of bank scour infilling rather than scouring of banks -- infilling of eggs in other areas and shifting of debris causing scour and loss of eggs and not with the gravel quality you found.

MR. SCRIVENER: Well, they're all correlated, that's the problem. You can show a relationship just as easily with peak flows, which is a measure of scour, if you want to use it for coho. It doesn't work for chums though, but it certainly works for coho. And I wouldn't even dream of trying to say that peak flows are the major reason for egg to fry survival, but they're well correlated. So changes in gravel quality are the major reason for any changes in survival or one of the reasons.

And there is one third of the spare area that's available for spawning above the intense treatment, so one third of the population of coho here are unaffected by the intense treatment area.

MR. HARDING: They're in the careful treatment area?

MR. SCRIVENER: Yes.

MR. HARDING: They're still in an area that demonstrated changes in channel morphology.

MR. HARRIS: Brian Harris, Fish and Wildlife. My question is to Charlie again.

Yesterday, I think Les told us that he found the greatest bank erosion occurred in the careful treatment area, in fact, somewhere in the magnitude of four times as much bank erosion, where your presentation this morning seemed to have a conflict with that, that the greatest bank erosion occurred in the intensive treatment area. Can you clear up that confusion?

MR. SCRIVENER: Yes, essentially the information I was showing here is only up to 1984. A lot of the material that Les was talking about is after that January '84 flood. So, the measurements I showed here of volume of material moved was before the influence of the 1984 flood. What Les was probably talking about is within the careful treatment after that January '84 flood.

MR. HARRIS: So there is no way to resolve between you two which is the preferred treatment for streamside practices?

MR. SCRIVENER: I don't think there's any difference. One simply takes longer for the system or for the stream to disintegrate, if you want to call it that.

MR. SHERA: Pat Shera. Another bank question for Charlie. Bank erosion; I may have missed the point somewhere along between yesterday and today. Did you correlate bank erosion to bank materials? I assume they're not homogeneous materials throughout, and one treatment area is in a canyon. With coarse materials, could that account for less bank erosion taking place there as compared to upstream in the intensive area?

MR. SCRIVENER: Les should probably answer that one, but there is certainly a bit of a control within one of the sections within the leave strip control by a canyon area, but there were two of the study sections within that that had no control. They were in the middle of the valley.

So if you look at specifically as a section, you could find differences accountable, but if you average them all together, I don't think that you can attribute all of the changes simply to one being controlled by a canyon. I didn't correlate any of the bank erosions, just total volume.

MR. POULIN: Charlie, I'd like to get back to what it all means again. You've indicated that there has been an increase in sedimentation of gravel quality, and you observed a decrease in egg to fry survival. What I'd like to know is what percent change have you seen in your survival values and how do you feel that percentage change attributed to sedimentation has had a net effect on the overall production of fry.

MR. SCRIVENER: Well, we haven't been able to separate all of those sorts of things. I haven't for chum. Blair will probably talk about some of that with coho. He identifies two major areas influencing coho egg to fry survival, and one of the major ones being scour and the second one being changes in gravel quality. It's all interrelated with flow regimes and hydrology of the system.

DR. WILLINGTON: Bob Willington. This is a collective question to all panel members to get off Charlie a bit.

I always have difficulty, particularly in the material presented, with before, during and after treatments on the same stream section. I wonder given the slides that Charlie showed yesterday and the comments made showing that there is quite a bit of channel morphology activity in "E" watershed, the control, and perhaps somewhat less but some activity in "C", what the character of the gravel quality change over time has been in those watersheds compared to the treatment watershed, so we can separate man-caused from natural changes in gravel?

MR. SCRIVENER: Well, essentially the two controls are much steeper watersheds, and the bed material is quite different. We haven't taken any gravel samples in either "E" or in "C".

We have upstream controls and where the careful treatment area was a control for a year or two after the intense treatment, then the system farther up was a control, or is a control after the debris torrent within the canyon and within the careful treatment. So, there are some partial controls.

DR. WILLINGTON: So then some of the results you would agree are both a combination of the natural event and those potentially induced by land use activities?

MR. SCRIVENER: I think that the hydrology of the system is the forcing factor. That's what's producing the impact. But the end result as an impact of man, it's purely a time thing. Sooner or later a freshet of the appropriate size will come along and make those changes. It's purely a temporal thing, when it occurs, but the situation, the scenario that's set up, the potential is created by the man-made activities.

MR. PENDRAY: Tom Pendray is my name. I guess this is a question for Bruno.

You were saying that there was quite a difference between your results on changes in suspended sediment compared to, was it the Alsea Study?

MR. TASSONE: Yes, that's correct.

MR. PENDRAY: Can you come to any conclusion as to why your results are different?

MR. TASSONE: Well, basically I think it's a function again of source material of the suspended sediments, as Eugene clarified earlier about the source of material, and the nature of the watershed. Most of the material that is available for transport is from basically in-channel supply rather than some of the other watersheds that have been studied.

A lot of the suspended material that's been found in the water course is from surface erosion off the land covered area, and obviously in Carnation Creek we are seeing far less material reaching the watershed from surface erosion. And I really see no impact from any of the logging road construction practices on suspended sediment material reaching the stream bed myself.

As also another comment, there had been a previous paper published by Ottens and Rudd about road construction impacts where they actually did take samples from channels near the roads, and they recorded quite high concentrations. They recorded quite a few samples that had concentrations greater than l,000 milligrams per liter of concentration. That's similar to the same days that those concentrations were recorded at "B" weir. We were only seeing concentrations of under l0 milligrams per liter.

Either it's a dilution factor from the road sources or that material, as Eugene as mentioned earlier, is not reaching the mainstem channel.

DR. CEDERHOLM: Jeff Cedarholm. Thank you. Since my name was mentioned earlier, I thought maybe I would help Charlie out a little bit with some of the explanation here.

I think that we have seen very similar kinds of processes going on in certain tributaries in the Clearwater River. You've got to remember Clearwater is a very large basin, and we're looking at a variety of kinds of situations.

Some of our tributaries are as large as Carnation Creek, for example, but generally speaking overall we think that what's going on in the Clearwater is the sedimentation changes in channel are related to the source areas that are being affected. And, for example, in Carnation Creek the roads are of a minor factor, at least at this point in time largely because of where they're located and also because of the geomorphology of the flood plain. It's flat country, and it's difficult for sediment to be delivered from the road directly into the channel.

Well, in the Clearwater, for example, the flood plains are very narrow, and the sediment is delivered directly into the channel. Now, our sediments are mainly coming from upslope areas where sediment particle sizes and the very fine sand, silt and clays and organic material are the largest part of the mass that's delivered. There's colluvium deposits high up on the slopes where roads are cutting through them and landslides are giving way, or the road surface is being a source of grinding from the trucks on the road surface itself. We found, as Charlie mentioned, both the landslides and the road surface were equal contributors of fine silts and sands.

Now, we've seen Charlie's situation in the Clearwater as well where roads are less of a factor, and you're having more of the sediment delivered from channel erosion. You're talking about old channel deposits of sometime in the past.

I think somebody mentioned either yesterday or earlier today that the stream has meandered across this flood plain for centuries, and the bank erosion is really recapturing of old gravel deposits. So you're talking about sediments in the larger particle categories because this has already been sorted over the centuries.

So the fine material is a lesser factor than the larger material. So this will explain why Charlie is finding changes in the larger material and less so in the fines, where our studies in the Clearwater were just the opposite. In our studies sediment was delivered from upslope moreso, and the finer particles are a greater part of the mass.

SESSION 3:
THE FOOD CHAIN

Moderator: Dr. C. Levings
Department of Fisheries and Oceans

CHANGES IN CONCENTRATION OF DISSOLVED IONS DURING 16 YEARS AT CARNATION CREEK, BRITISH COLUMBIA

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This paper describes the patterns of dissolved ions at the main flow guaging weir and at weirs in four subbasins in Carnation Creek watershed. The patterns are interpreted in relation to logging and slash burning. Two subbasins remained unlogged between 1971 and 1986 (tributaries C and E). Another was logged and burned in 1977 (tributary J), and a fourth was logged during 1978, but it was not burned (tributary H). Analysis is by water year which began in October and ended with low flow the following September. These studies ended with completion of phase I in 1986.

RESULTS AND DISCUSSION

A consistent seasonal pattern was observed for the dominant positively (calcium, sodium, magnesium) and negatively (bicarbonate, silicate) charged ions that were dissolved in the stream. There were pronounced concentration peaks in summer and autumn, with lower values in winter and early spring (Scrivener 1975). Lower concentrations also occurred during months of high stream discharge, while higher values occurred during summer or autumn low flows (Scrivener 1982). Their concentrations were lower than those observed in U.S. streams (Brown et al. 1973; Likens et al. 1967; Vitousek 1977), but they were similar to those in another cedar-hemlock forest in British Columbia (Feller 1977). Many of these ions originate from weathering of bedrock in a watershed (Bormann and Likens 1979; Likens et al. 1977).

Electrical conductivity can be used as an indicator of the quantity of these dominant ions in Carnation Creek. The greater the conductivity the more dissolved ions that the stream contained. Conductivity was low and inversely related to stream flow at all sites during each water year (Scrivener 1975, 1982). In the main stream, the greatest conductivities occurred during 1978/79 and 1979/80 after logging and slash burning was begun (Fig. 1). Conductivity was also inversely related to stream flow during individual freshets (Scrivener 1982). If these storms occurred after long dry periods, then conductivities tended to be greater than the annual average, but if they occurred during a period of frequent storms, conductivities were lower (Fig. 2). Concentrations of the dominant ions appeared very flow regulated at Carnation Creek. Ion concentrations were not as flow regulated in either Hubbard Brook, New Hampshire (Likens et al. 1977) or Alsea, Oregon (Brown et al. 1973), where logging impacts were also studied.

Five conclusions summarize the impacts of logging and silvicultural practises on conductivity at

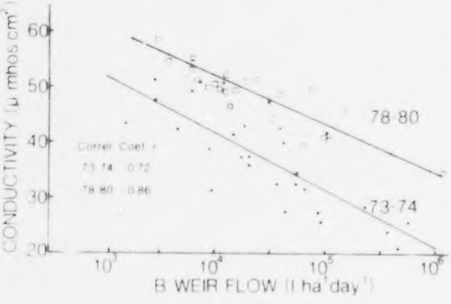

Figure 1. Relationships obtained between B weir conductivity and discharge for October 1, 1973 to September 30, 1974 and October 1, 1978 to September 30, 1980 at Carnation Creek. Dots represent samples from 1973/74, while squares are samples from 1978/80.

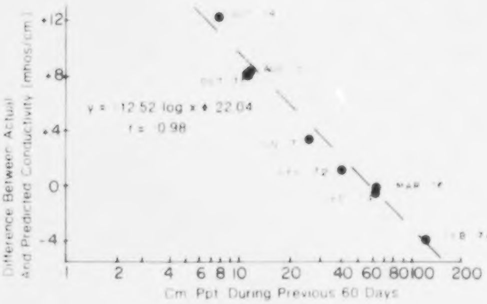

Figure 2. The relationship between prelogging stream conductivity and the previous hydrolgical flux at B weir in Carnation Creek watershed.

Carnation Creek. They can be illustrated by plotting, through time, the annual relationships between stream flow and conductivity at all 5 weirs (Figs. 3, 4).

1. The impacts were modest with a maximum increase of 90% at high flows only in tributary J, the most intensively logged and burned watershed (Fig. 4). A maximum increase of 50% occurred during high flows in the main channel (B weir; Fig. 3).

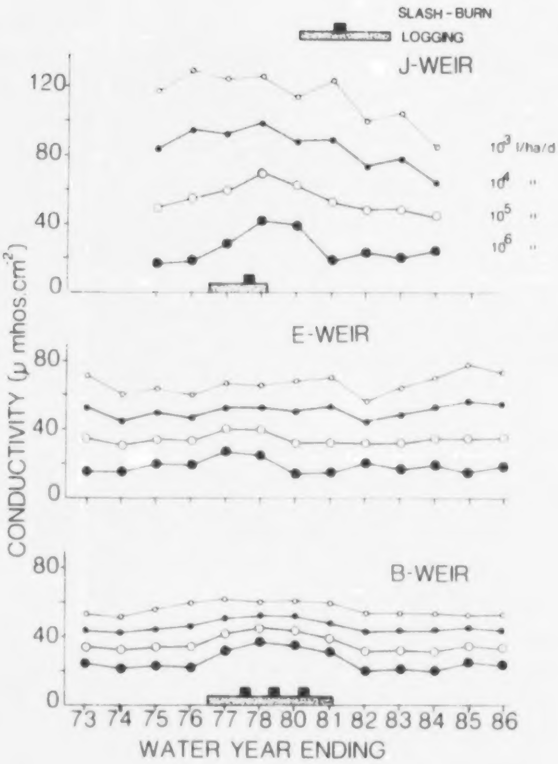

Figure 3. Changes of conductivity in the main stream (B), in a logged and burned tributary watershed (J) and in an undisturbed tributary (E) during 16 yrs of the Carnation Creek watershed study. Conductivities were calculated at high (large dots), medium high (large circles), medium low (small dots), and low discharges (small circles) from annual relationships between conductivity and stream flow.

2. These increases were restricted to high or moderate flow levels. Little or no increase was observed at low flows during the summer. After 1981, conductivities actually declined during low flows in tributary J (Fig. 3).

3. Increases occurred a year after logging and slash burning were begun in each watershed.

4. Conductivities appeared to return to prelogging levels within 2 years after forest harvesting had ceased in the watersheds (Fig. 3).

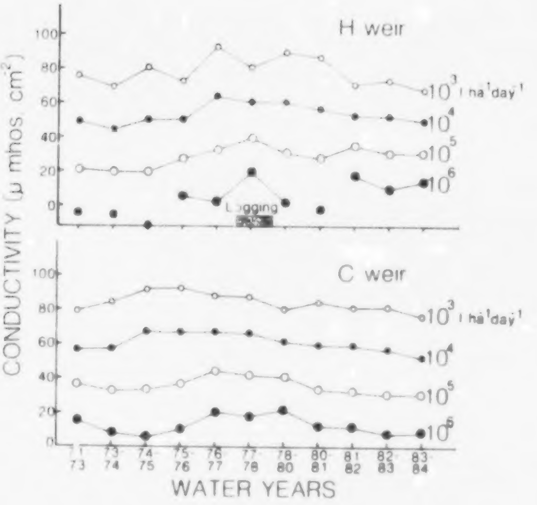

Figure 4. Conductivities in tributaries C and H during the Carnation Creek watershed study. They were calculated from annual relationships between conductivity and stream flow for high (large dots), medium high (large circles), medium low (small dots), and low discharges (small circles).

5. Conductivities might return to prelogging levels at a slower rate if logging slash was not burned. During storm flows at H weir, conductivities returned to prelogging levels between 1978 and 1981, but they appeared to increase slightly again during 1982 to 1984 (Fig. 4).

During 16 years, conductivities changed little in tributaries C and E, the unlogged controls. The slope of the relationship between conductivity and stream flow changed only slightly from year to year as indicated by divergence or convergence of the points representing low to high flows (Figs. 3, 4). A slight increase appeared for high flows during 1976/77 and 1977/78 at both sites. This was probably caused by the reduced number of storms and lower precipitation (Hetherington 1982) during these two water years.

Nitrate, a stream nutrient, was also influenced by stream discharge and by forest practises. Like other dominant ions, nitrate concentration was inversely related to stream flow during each water year, but nitrates were flushed from the watershed during the first autumn storms (Scrivener 1982). Nitrate concentrations were either unrelated to flow (prelogging) or they became positively related to flow (post burning) during these storms (Fig. 5). Unlike many dominant ions, the sources of nitrate were from input in precipitation, from "nitrogen fixation" by bacteria on the roots of vegetation (atmospheric nitrogen converted to nitrate in the soil), and from rotting vegetation in the soils (Bormann and Likens 1979; Vitousek 1977; Vitousek et al. 1982). Therefore soil and vegetative cover types influenced nitrate availability to the stream.

The impacts of forest harvesting and silvicultural practises on nitrate concentrations in the stream can be summarized as five points.

1. The impacts were relatively modest. Nitrate concentrations increased ~2 times at Carnation Creek (Fig. 6), while they increased ~10 times at Hubbard Brook (Bormann et al. 1974) and ~5 times at Alsea watershed (Brown et al. 1973).

2. The first impacts occurred a year after logging was begun (Fig. 6).

3. Unlike conductivity, nitrate concentrations increased over the full range of stream flow. At low flows, they were not greater than prelogging concentrations until 3 years after logging and slash burning was initiated (Fig. 6).

4. These increases were of short duration. Elevated nitrate values continued for 7 years at high flows, but they continued for only 2 years at low flows (Fig. 6). At high to moderate flows, nitrate concentrations had returned to prelogging levels within 3 years of the termination of forest harvesting activities at Carnation Creek.

5. Nitrate concentration tended to decline below prelogging values by the end of the study. This was observed for only low to moderate flows that occurred from 3 to 5 years after forest harvesting had ceased (Fig. 6).

In tributary E, a control site, nitrate concentrations were variable, but no trend was apparent during 16 years of monitoring. Differences in concentration between high and low flows were reduced during 1976/77 and 1977/78 which were years with less precipitation and fewer storms (Fig. 6). The greatest range of concentrations occurred during 1980/81, a wet year with frequent storms. This divergent and convergent pattern in range of concentrations was

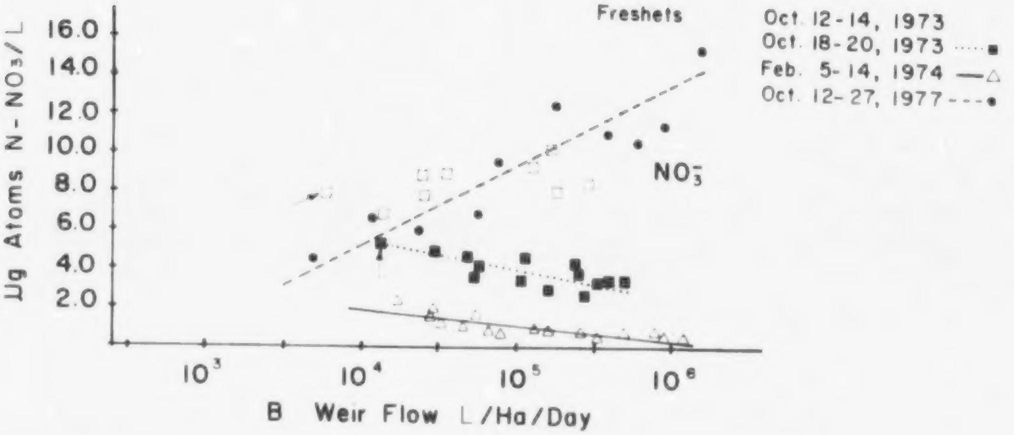

Figure 5. Relationships obtained for nitrate-N concentrations verses steam flow during 4 freshets in Carnation Creek. Arrows indicate concentrations at the beginning of the October 12-14, 1973 (solid) and of the October 18-20, 1973 (stippled) freshets.

also observed, but less pronounced in the main stream (B weir; Fig. 6).

The pattern of another nutrient, phosphate, was very different. Phosphate concentrations were very low throughout the study and they were unrelated to stream flow (Scrivener 1975, 1982). No seasonal pattern was observed for this ion. Concentrations of total dissolved phosphate remained unchanged in the main stream during the period of logging and slash burning (Fig. 7). Although during this period, the higher concentrations of phosphate occurred for samples that were collected immediately after burns (Scrivener 1982). Subsequently, they declined after forest harvesting had ceased in the watershed (Fig. 7). This reduction could have occurred because of increased uptake by algae in the stream (Shortreed and Stockner 1982), and/or because of increased demand by the regenerating forest (Gorham et al. 1979). Phosphate concentrations were unchanged during 15 years of the Alsea watershed study (Brown et al. 1973).

MANAGEMENT IMPLICATIONS

Removal of vegetation, disturbance of soils, and burning of logging slash released more ions and nutrients that could then be leached from the soil by water passing through it to the stream. Smaller quantities of these ions reached Carnation Creek than those reported during other studies (Brown et al. 1973; Likens et al. 1977). Either fewer nutrients were released, possibly because soils are shallow, or the soils were capable of better retention, possibly because of their high organic content. Nutrients that could be leached were more rapidly routed to the stream during the frequent storms. Ion concentrations in the stream then declined to prelogging levels within time periods that were shorter than those reported for other studies (Brown et al. 1973; Likens et al. 1977). Since the magnitude and duration of increase was so small no short term detrimental effect occurred in the stream.

Stream production is dependent on inputs of leaves from deciduous trees (alder) and of needles from conifers. This detritus and its bacterial decomposers are the base of the food chain in streams of forested watersheds. Detritus should be most important during autumn and winter when it is entering or it is being processed by the stream (Neaves 1978). With the exception of summer months, low light intensities from canopy shading, low nutrients, and high scouring during frequent freshets make algal production a minor source of energy for stream productivity in undisturbed watersheds (Kaushik and Hynes 1968; Shortreed and Stockner 1982).

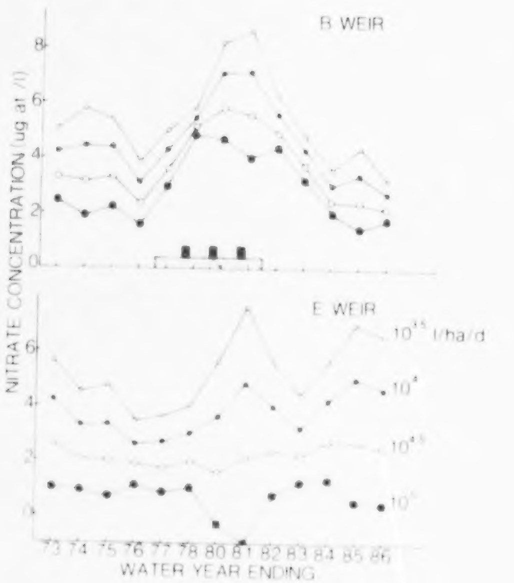

Figure 6. Nitrate-N concentrations in the main stream (B) and an undisturbed tributary (E) during the Carnation Creek study. They were calculated from the annual relationships between nitrate and stream flow at 4 discharges.

Clearcutting of the forest greatly reduces material that forms detritus, but it increases light intensities, nutrients and algal production in streams (Murphy and Hall 1981). Although different qualitatively, increased algal production is a counter balance to the loss of leaf input, but only during the summer. Algal production did not increase in Carnation Creek, despite increased light intensity because phosphate was the primary limiting factor (Shortreed and Stockner 1982). Declining nitrates and phosphates 3 to 5 years after forest harvesting suggest that declining algal production can be anticipated. Leaf litter inputs will increase again as streamside vegetation regenerates, but until this occurs, the production base of the food chain may be declining. This is relevant to the production of rearing salmon only if food is a major limiting factor for them.

ACKNOWLEDGEMENTS

Assistance in the field by many individuals during the last 16 years is gratefully acknowledged. Most of the chemical analyses were done by Messrs. K. Stephens, T. Nason, J. Davidson, P. Kluckner and members of the E.P.S. chemistry laboratory in West Vancouver. Without their contribution this work could not have been funded.

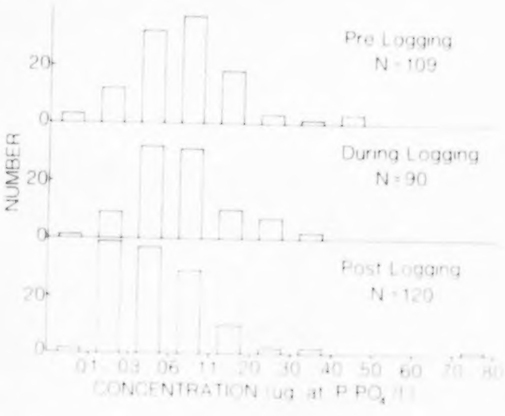

Figure 7. Phosphate-P concentrations observed in Carnation Creek during prelogging, forest harvesting, and post harvesting phases of the study.

REFERENCES

Bormann, F. H., G. E. Likens, T. G. Siccama, R. S. Pierce, and J. S. Eaton. 1974. The export of nutrients and recovery of stable conditions following deforestation at Hubbard Brook. Ecol. Monogr. 44: 255-277.

Brown, G. W., A. R. Gahler, and R. B. Marston. 1973. Nutrient losses after clear-cut logging and slashburning in the Oregon coast range. Water Resour. Res. 9: 1450-1453.

Feller, M. C. 1977. Nutrient movement through western hemlock - western redcedar ecosystems in southwestern British Columbia. Ecology 58: 1269-1283.

Gorham, E., P. M. Vitousek, and W. A. Reiners. 1979. The regulation of chemical budgets over the course of terrestrial ecosystem succession. Ann. Rev. Ecol. Syst. 10: 53-84.

Hetherington, E. D. 1982. A first look at logging effects on the hydrologic regime of Carnation Creek experimental watershed, p. 36-44. In:

G.F. Hartman [Ed.]. Proceedings of the Carnation Creek Workshop, a 10-year review. Pacific Biological Station, Nanaimo, British Columbia. 404 p.

Kaushik, N. K., and H. B. N. Hynes. 1968. Experimental study on the role of autumn-shed leaves in aquatic environments. J. Ecol. 56: 229-243.

Likens, G. E., F. H. Bormann, N. M. Johnson, and R. S. Pierce. 1967. The calcium, magnesium, potassium and sodium budgets for a small forested ecosystem. Ecology 48: 772-785.

Likens, G. E., F. H. Bormann, R. S. Pierce, J. S. Eaton, and N. M. Johnson. 1977. Biogeochemistry of a forested ecosystem. Springer-Verlag, New York, N.Y., U.S.A. 146 p.

Murphy, M. L. and J. D. Hall. 1981. Varied effect of clear-cut logging on predators and their habitat in small streams of the Cascade Mountains. Can. J. Fish. Aquat. Sci. 38: 137-145.

Neaves, P. I. 1978. Litter fall, export, decomposition, and retention in Carnation Creek, Vancouver Island. Fish. Mar. Ser. Tech. Rep. 809: 45 p.

Scrivener, J. C. 1975. Water, chemistry, and hydrochemical balance of dissolved ions in Carnation Creek watershed, Vancouver Island, July 1971 to May 1974. Can. Fish. Mar. Serv. Tech. Rep. 564: 141 p.

Scrivener, J. C. 1982. Logging impacts on the concentration patterns of dissolved ions in Carnation Creek, p. 64-80. In: G.F. Hartman [Ed.]. Proceedings of the Carnation Creek Workshop, a 10-year review. Pacific Biological Station, Nanaimo, British Columbia. 404 p.

Shortreed, K. S. and J. G. Stockner. 1982. The impact of logging on attached algal biomass and species composition in Carnation Creek: a coastal rain forest stream on Vancouver Island, B.C., p. 197-209. In: G.F. Hartman [Ed.]. Proceedings of the Carnation Creek Workshop, a 10-year review. Pacific Biological Station, Nanaimo, British Columbia. 404 p.

Vitousek, P. M. 1977. The regulation of element concentrations in mountain streams in northeastern United States. Ecol. Monogr. 47: 65-87.

Vitousek, P. M., J. R. Gos, C. C. Grier, J. M. Melillo, W. A. Reiners. 1982. A comparative analysis of potential nitrification and nitrate mobility in forest ecosystems. Ecol. Monogr. 52: 155-177.

THE AUTOTROPHIC COMMUNITY RESPONSE TO LOGGING IN CARNATION CREEK, BRITISH COLUMBIA: A SIX YEAR PERSPECTIVE

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INTRODUCTION

The autotrophic periphyton (attached algal) communities of streams are very sensitive indicators of stream water quality and are the first biotic stream community to respond to perturbations in the drainage basin. Over a six year period (I974-I979) we investigated the impact of logging on the species composition, biomass and production (accumulation rate) of periphyton on artificial substrates in Carnation Creek at 7 stations (Fig. I). Methods used and the major results and conclusions of this work are presented in three published papers (Stockner and Shortreed I976, Stockner and Shortreed I978, Shortreed and Stockner I983).

There are both physico-chemical and biological variables that can affect the distribution and abundance of periphyton in streams. Logging, a major perturbation of the drainage basin, would be expected to alter the impact of these variables on all biotic communities within Carnation Creek. Our overall study conclusion was that there was little change from pre-logging values in accumulation rate (growth) or biomass of periphyton as a result of logging conducted during the final 3 years of our study (I977-79).

For purposes of this workshop presentation, we have summarized the impact of physico-chemical and biological variables on periphyton communities in Carnation Creek during our 6 year study period.

A. Physical Variables

Temperature - Though mean summer temperatures in Carnation Creek increased by 2-3°C after logging we did not consider this change to be large enough to affect the physiological growth and respiration requirement of attached algae and therefore the accumulation of biomass.

Light - initially we considered that forest canopy removal and the attendant increased light on the streambed should markedly influence growth and biomass of periphyton in Carnation Creek. However, after logging biomass of periphytor (as measured by chlorophyll) remained similar in shaded and unshaded areas of the streambed and the general lack of response to post-logging light increases suggests to us that light was not a critical variable limiting periphyton production in Carnation Creek.

Flow - While flow had little influence on periphyton biomass during the growing season (when flows were low and stable), it did limit the duration of the growing season. The final spring freshet and the first autumn freshet effectively delineated the growing season, although occasional low flow periods of several weeks' duration occurred in winter, and resulted in measurable accumulations of periphyton. When flows were high and variable, losses by scouring were considerable, and periphyton could not colonize the substrate (Fig. 2).

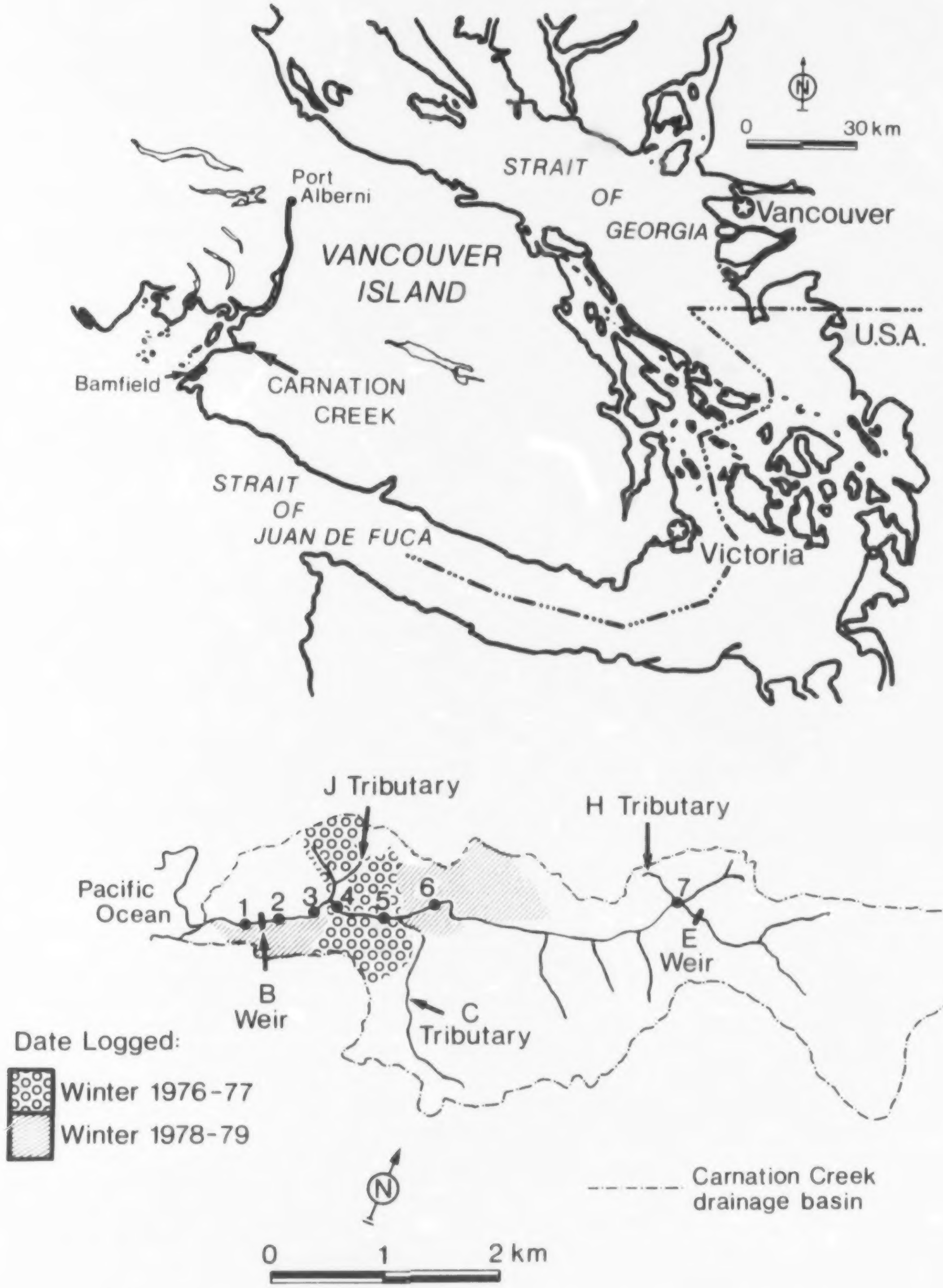

Figure 1. Map of study area and major logging areas within the Carnation Creek drainage basin.

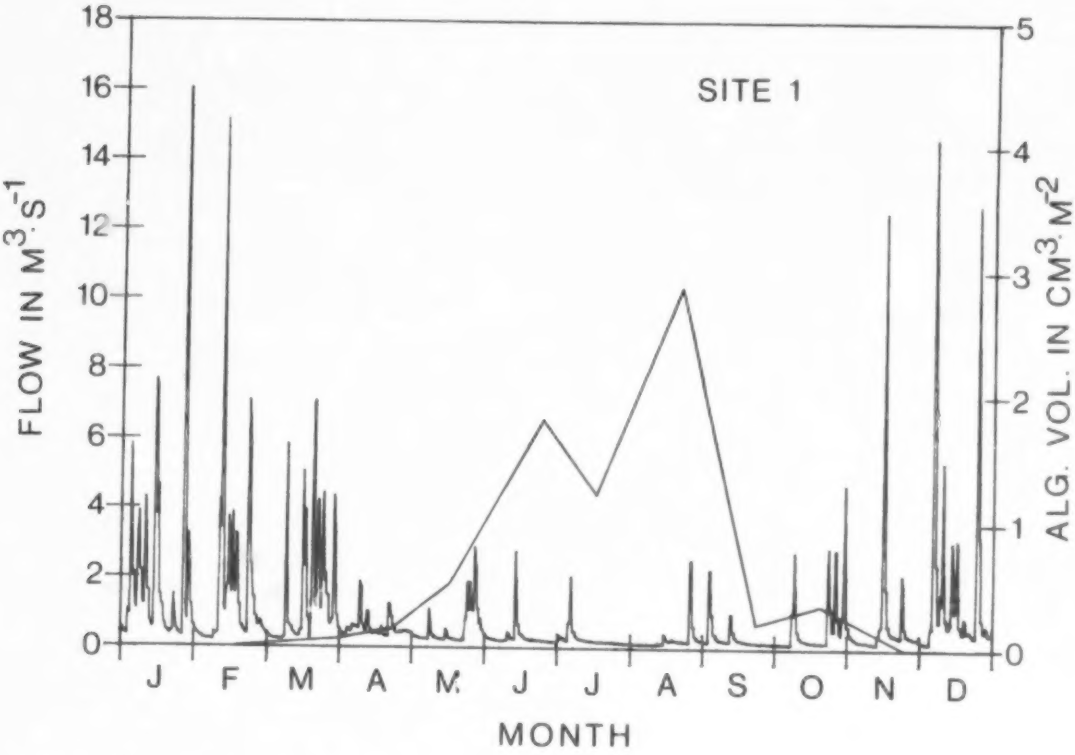

Figure 2. Annual Hydrograph (1976) and attached algal volume for Site 3 during that year.

Substrate quality - Logging activity, particularly the removal of streamside vegetation, contributed to destabilization of the streambank in Carnation Creek, increased erosion, and a consequent increase in the amount of sediment entering the stream. Scrivener and Brownlee (1980) found an increase in the amount of material <9 mm in diameter in the top layer of gravel in Carnation Creek. This post-logging increase of smaller material has been observed in a number of other systems and has generally had a deleterious effect on stream biota. Whereas the samplers used in this study were not affected by substrate size (at least during low flow periods), in some sections of the creek periphyton biomass on natural substrate may have been affected by the reduction in size of natural substrate. We have no direct observations to validate this conjecture, but we feel that the increase in small diameter particulates increased abrasion and scouring of periphyton and can only be considered as detrimental to autotrophic production.

B. Chemical variables

Nutrients - There were no significant shifts in the concentrations of conservative elements and ions in Carnation Creek between pre and post-logging years; however, there were some changes in dissolved nutrient concentrations, with nitrogen exhibiting the greatest change (Scrivener 1983). Marked increases in dissolved inorganic nitrogen concentrations after logging and slash burning have been detected in a number of studies (Brown et al. 1973; Likens et al. 1970), and were also found in Carnation Creek (Scrivener 1983). The lack of periphyton response to these nutrient increases corroborated our earlier conclusions, where we found in a nutrient enrichment experiment that increased nitrate concentrations had no effect on either periphyton biomass or species composition in wooden troughs carrying Carnation Creek water (Stockner and Shortreed 1978).

Although post-logging concentrations of dissolved phosphorous in Carnation Creek were more variable than pre-logging values, pre and post-logging averages were similar, and significant increases did not occur after logging (Scrivener 1983). Throughout the study, any detected increases in dissolved phosphorous concentrations occurred during freshets, when scouring of the streambed (and of the samplers) precluded any periphyton response to increased nutrient concentrations. In an earlier paper (Stockner and Shortreed 1976) we hypothesized that phosphorous was the primary factor limiting periphyton growth rates and biomass in Carnation Creek, and later demonstrated (Stockner and Shortreed 1978) that additions of phosphorous (either alone or with nitrogen) increased periphyton biomass while additions of nitrogen only did not. The relatively large changes in some evironmental factors (light and nitrate) which occurred after logging, and the lack of a periphyton response to these changes (Fig. 3), lend support to the earlier hypothesis that during low flow periods, phosphorus is the major factor limiting periphyton production and biomass in Carnation Creek.

C. Biological Variables

Grazing - Although grazing by benthic invertebrates can play a major role in controlling periphyton biomass and production in some systems, it did not appear to be of any significance in Carnation Creek. Qualitative examination of the gut contents of stream benthos (J.C. Scrivener, unpublished data) indicated that while periphyton were utilized, allochthonous detritus was the major food resource. In addition, Culp (1982) found that invertebrate densities were highest in portions of the stream which had the highest standing crops of benthic detritus. Finally, it is unlikely that changes in the invertebrate community after logging would have masked changes in the periphyton community since the density of stream invertebrates was significantly reduced after logging (Culp 1982).

Species composition - During our 6-yr study diatoms remained the dominant taxa and the same species were dominant throughout the study (Fig. 4). Attached filamentous green algae (*Mougeotia*, *Draparnaldia*, *Spirogyra*), became more common after logging. In a clear-cut logged stream (Ritherdon Creek) adjacent to Carnation Creek, which had similar nutrient concentrations, filamentous greens were more common than in Carnation Creek prior to logging (Stockner and Shortreed 1976). In addition, although a nutrient enrichment experiment prior to logging in the Carnation Creek drainage basin increased periphyton biomass (Stockner and Shortreed 1978), the relative abundance of filamentous greens did not increase under the experimental conditions (low light, increased nutrients). The similarity of the filamentous green response to logging in Carnation Creek and in Oregon streams, despite widely different water chemistry between systems, is evidence of their greater affinity for high light intensities than many other species of stream periphyton, regardless of ambient nutrient levels.

CONCLUSION

We conclude that environmental factors that were changed as a result of logging (light intensity, nitrogen concentration, sediment load) had little effect on the periphyton community, because the major limiting factor, phosphorus concentration, was not generally affected. Changes observed in stream benthos and in the stream fish community after logging (Culp 1982; Holtby and Hartman 1982) were clearly a result of changes in the physical environment (increased streambank erosion and temperature), rather than a result of changes in periphyton biomass or species composition. In nutrient-limited, fast-flushing coastal streams such as Carnation Creek, physico-chemical variables are the dominant factors regulating biotic production. The hydrologic regime (flow) sets the limits of autotrophic production for much of the year and consideration should be given to periphyton growth enhancement by stream fertilization during those periods when flow is low and stable and nutrients are likely scarce and limiting.

REFERENCES

Brown, G.W., A.R. Gahler, and R.B. Marston. 1973. Nutrient losses after clear-cut logging and slash burning in the Oregon Coast Range. Water Resource Res. 9(5): 1450-1453

Culp, J.M 1982. The ecological effects of logging on the macroinvertebrates of a salmon stream in British Columbia. Ph.D. thesis, Univ. of Calgary,Calgary, Alta. 157 p.

Holtby, L.B., and G.F. Hartman. 1982. The population dynamics of coho salmon (*Oncorhynchus*

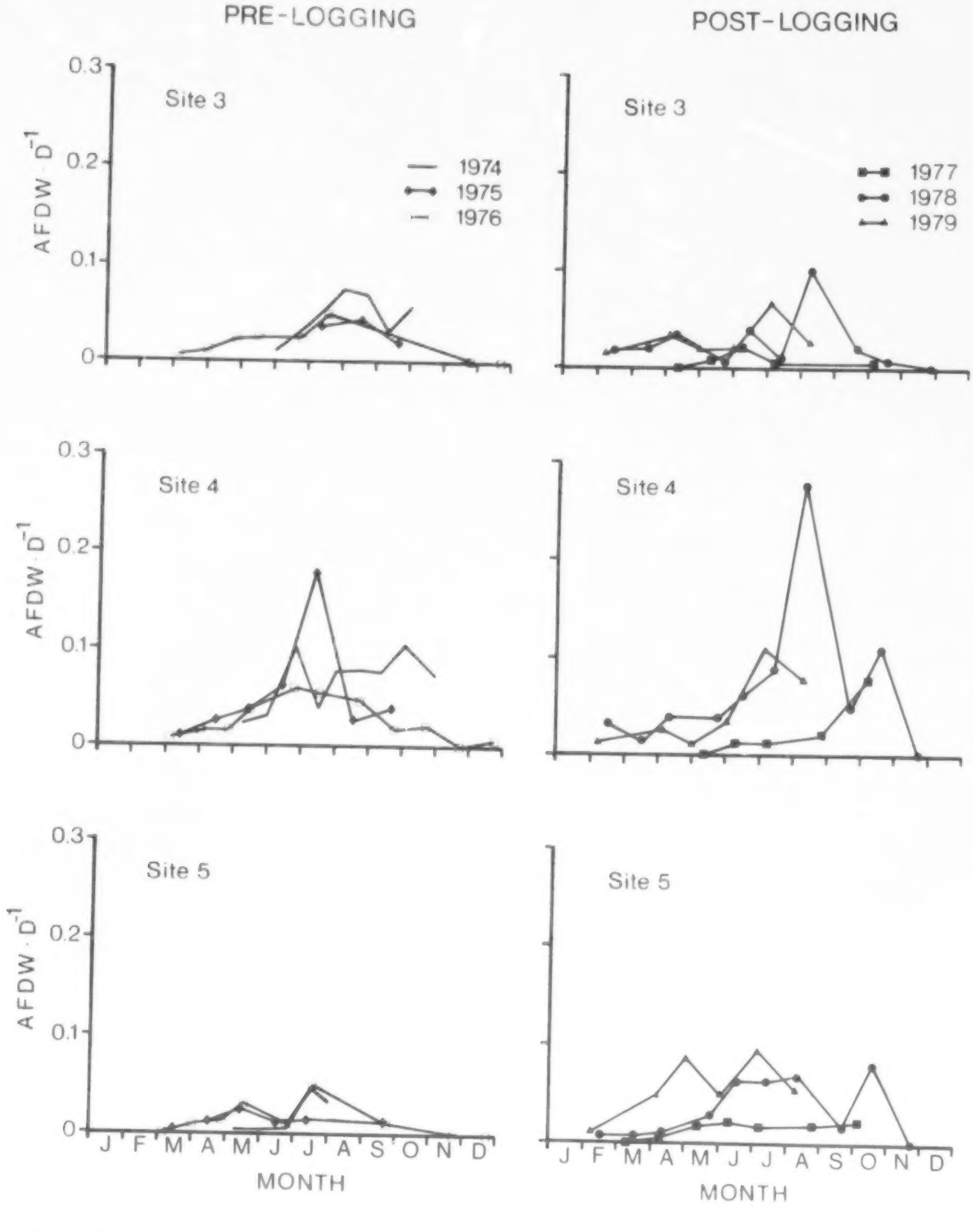

Figure 3. Seasonal variation of attached algal accumulation rates at three sites during pre-logging (1974-76) and post-logging (1977-79) portions of the study (AFDW = ash-free dry weight).

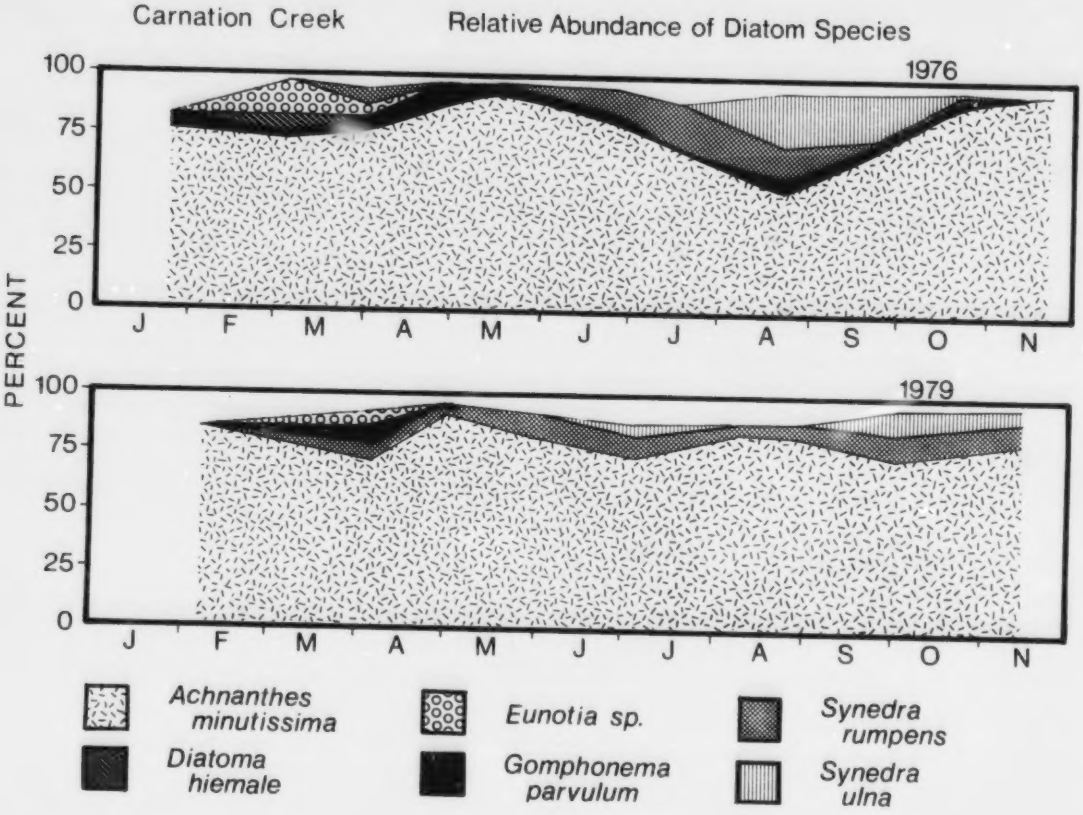

Figure 4. Relative abundance of major diatom species at Site I during 1976 (pre-logging) and 1979 (post-logging).

kisutch) in a west coast rain forest stream subjected to logging, p. 308-347. In G.F. Hartman [Ed.] Proceedings of the Carnation Creek Workshop, a 10 year review. Pacific Biological Station Nanaimo, British Columbia. 404 p.

Likens, G.E., F.H. Bormann, N.M. Johnson, D.W. Fischer and R.S. Pierce. 1970. Effects of forest cutting and herbicide treatment on nutrient budgets in Hubbard Brook watershed-ecosystem. Ecol. Monogr. 23-47.

Scrivener, J.C. 1983. Logging impacts on the concentration patterns of dissolved ions in Carnation Creek, British Columbia, p. 64-80. In G.F. Hartman [Ed.] Proceedings of the Carnation Creek Workshop, a 10 year review. Pacific Biological Station Nanaimo, British Columbia. 404 p.

Shortreed, K.S., and J.G. Stockner. 1983. Periphyton biomass and species composition in a coastal rainforest stream in British Columbia: effects of environmental changes caused by logging. Can. J. Fish. Aquat. Sci. 40: 1887-1895.

Stockner, J.G., and K.S. Shortreed. 1976. Autotrophic production in Carnation Creek, a coastal rainforest stream on Vancouver Island, British Columbia. J. Fish. Res. Board Can. 33: 1553-1563.

Stockner, J.G., and K.S. Shortreed. 1978. Enhancement of autotrophic production by nutrient addition in a coastal rainforest stream on Vancouver Island. J. Fish. Res. Board Can. 35: 28-34.

THE EFFECTS OF STREAMBANK CLEARCUTTING ON THE BENTHIC INVERTEBRATES OF CARNATION CREEK, BRITISH COLUMBIA

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INTRODUCTION

Clearcut logging operations around 1st-3rd order coastal streams can produce significant changes in the abiotic and biotic environmental components of stream ecosystems. Although fish populations of these streams have been studied extensively, little attention has been given to determining the effect post-logging enviromental changes have on their benthic macroinvertebrate food source.

Numerous abiotic changes to the stream environment occur as the result of logging operations in watersheds around coastal streams, but post-logging shifts in stream discharge, bank stability, sedimentation, insolation, water temperature and the terrestrial release of inorganic nutrients are often cited as having the most potential for detrimentally affecting macroinvertebrate communities. On the other hand, the dominant biotic impacts of logging on macroinvertebrates are related to shifts in allochthonous (e.g., leaf litter) and autochthonous (e.g., algal production) energy input. These shifts in the trophic structure of the stream may directly or indirectly change the amount and quality of food resources available for the macroinvertebrates.

The macroinvertebrate study in Carnation Creek investigated the effects of two different logging treatments on macroinvertebrate communities during the initial three year period after logging. In the site 630 m stream reach, logging followed normal west coast logging practices with adherence to the British Columbia Forest Service Watershed Protection Clause (P1). Clause P1 states that trees shall not be felled into or yarded through the stream, but allows merchantable timber to be removed from around the stream by using jacks and cables (MacMillan Bloedel Ltd. 1979). Therefore, logging operations at site 630 m left a partial leave strip (i.e., buffer zone) of forest that contained only non-merchantable timber.

Clause P1 was waived along the site 1480 m stream reach (MacMillan Bloedel Ltd. 1979), and this resulted in a more severe logging treatment with the forest clearcut to the streambank. Additionally, all the merchantable timber debris in the stream prior to logging was removed during the yarding process (Toews and Moore 1982). Thus, without the P1 clause in effect, logging activities were not just restricted to clear-cutting the streambank, but also included the removal of many of the large, stable debris dams along the site 1480 m stream reach.

EFFECTS OF CLEARCUTTING

A major abiotic impact of logging on the Carnation Creek stream ecosystem was the rapid streambank erosion along the stream reach without a buffer zone (site 1480 m). This sediment input caused a significant increase in the proportion of < 9 mm sediments in the substrate, and the downstream transport of these < 9 mm sediments by suspension and saltation also increased their proportions in the reach with a buffer zone and stable streambanks (site 630). Although within three years re-vegetation of the clearcut streambanks was complete and sediments < 2.38 mm were flushed away (Scrivener and Brownlee 1980), logging without a buffer zone channelized this reach, thus, the post-logging streambed will be scoured more frequently than before logging. Because streambank destabilization was the major source of increased post-logging sedimentation in Carnation Creek, apparently the observed increase in sediments could have been prevented by leaving a 10 m wide buffer zone on the stream bank and natural debris dams (i.e., logging with P1 clause restrictions).

Road construction is generally recognized as a major source of logging- related sedimentation (Gibbons and Salo 1973), but in Carnation Creek this was not observed because roads were placed well away from the stream. Although suspended sediments may have been temporarily increased during rainstorms at the time of road construction, the proportion of fine sediments in the streambed substrate was not affected by these short-term increases of suspended sediments (Towes personal communication). Unlike other streams, post-logging mass-wasting (e.g., slumping or landslides) in the watershed has not been near enough to the stream to cause sedimentation to the streambed (Hartman personal communication) during this period.

Logging increased the light available for photosynthesis by opening the forest canopy but, as compared to pre-logging estimates, post-logging algal biomass did not significantly increase because phosphorus remained the limiting factor for primary production (Shortreed and Stockner 1983). In contrast to the coastal streams of California and Oregon, post-logging autochthonous primary production in Carnation Creek did not counterbalance the significant post-logging loss of allochthonous leaf litter input.

Since logging significantly reduced the input of deciduous and coniferous leaf litter to the stream even in the reach with a buffer zone (Fig. 1), the standing crop of benthic detritus also decreased at both logged sites (Culp and Davies 1983). However, the post-logging decrease was significantly less in the reach with a buffer zone. If buffer zones are to maintain the normal levels of allochthonous input and benthic detritus standing crop observed for coastal streams, the data from the initial three-year postlogging period indicate the width of the buffer strip must be wider than the 10 m zone left along Carnation Creek. Further measurements are needed in order to determine the time-span over which this post-logging reduction in detritus is expected to be observed.

Clearcutting of the Carnation Creek watershed did not alter the seasonal trends of macroinvertebrate community (species) composition (Culp and Davies 1983). Throughout the pre- and post-logging period, the seasonal changes in benthic composition were strongly affected by the seasonal periods of high and low discharge. During the high discharge period (November to March), scouring reduced densities of all benthic macroinvertebrate taxa and changed benthic community composition by reducing the densities of some taxa more than others. Densities of most taxa increased during the low discharge period (April to October), as the macroinvertebrate species in Carnation Creek have adapted their life histories to utilize this annually recurring period of maximum food abundance and substrate habitat stability for the time of maximum growth and reproduction.

The winter was an annually recurring period of streambed perturbation and low benthic density, but, at site 1480 m without a leave strip, winter scouring caused greater decreases in macroinvertebrate density after logging because of the increased input of < 9 mm sediments from the eroded streambanks (Culp and Davies 1983). During the summer, density reductions at this site were related to the reduced allochthonous energy input.

Downstream transport of the < 9 mm sediments eroded from the streambank at site 1480 m also apparently caused density reductions in the winter at site 630 m (Culp and Davies 1983). Nevertheless, the effects of winter scouring were less severe at site 630 m because of the buffer zone and the retention of the natural debris dams. The detrimental effects of logging on macroinvertebrates were also reduced by the buffer strip at site 630 m in the summer, presumably due to the higher allochthonous input from the streambank.

EXPERIMENTAL MANIPULATION OF SUBSTRATE AND DETRITUS

Substrate particle sizes ranging from homogenous gravel to a heterogenous mixture of gravel, pebbles and cobbles did not significantly affect the biomasses or densities of most macroinvertebrate taxa (16 of 19) when detritus quality and quantity in the different substrate mixtures was standardized (Culp et al 1983). In the pebble and cobble substrate without the standardized detritus, macroinvertebrate

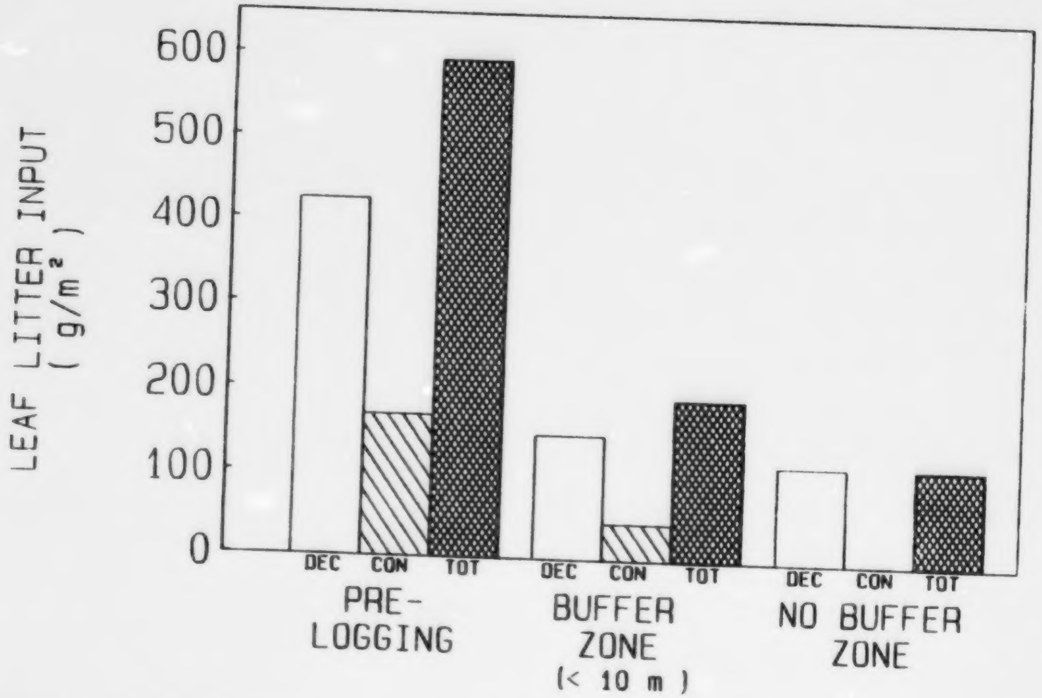

Figure 1. The deciduous (DEC), coniferous (CON), and total (TOT) leaf letter inputs (g/m^2) before logging and at post-logging sites with and without a buffer zone.

biomass and density was significantly lower as compared to the identical substrate with detritus added. Thus, the prime importance of detritus as a microdistribution factor was established, and it was concluded that the differential colonization of substrates demonstrated for macroinvertebrate taxa in other substrate experiments was due to differences in organic sedimentation, rather than to differences in substrate particle size composition. Since the substrate particle size range used in the Carnation Creek experiment was similar to therange found in natural riffles, logging-related changes in substrate composition would not significantly alter macroinvertebrate biomass or density, except when sedimentation reduced the amount of habitat available to macroinvertebrates.

Manipulation of detritus quality and quantity in a substrate of fixed composition further demonstrated that macroinvertebrate microdistribution was significantly affected not only by the quantity of detritus, but also by detritus quality (Culp and Davies 1983, 1985; Fig. 2). Generally, alder was a high quality detritus and hemlock was low quality, but the responses to detritus quality and quantity varied between taxa. The responses were not always predictable, even among members of the same functional feeding groups. However, from this experiment it is clear that significant decreases in benthic detritus quantity which can result from clearcutting the riparian vegetation (particularly deciduous vegetation) have the potential to decrease detritivore density and biomass.

EXPERIMENTAL MANIPULATION OF SEDIMENTS

Field experiments were conducted to examine the response of the benthos to deposited as well as transported sediments. Sand deposition had no measurable impact on most taxa (Fig. 3), the only negative effects being significantly higher drift rates and lower benthic densities of *Paraleptophlebia*. However, sediment transport by saltation created a

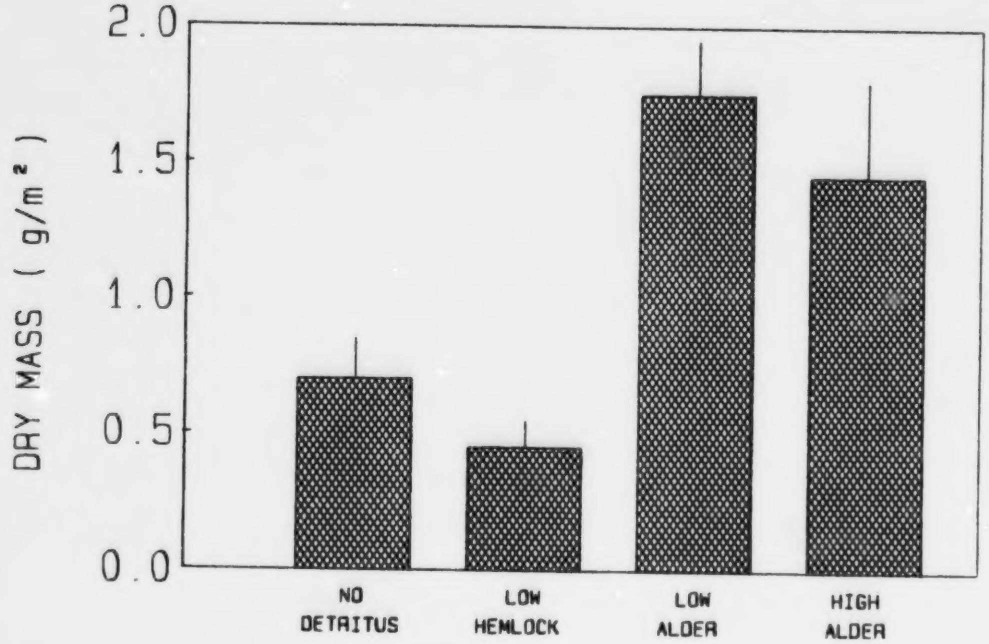

Figure 2. Mean (±SE) macroinvertebrate densities in standardized stone substrates with four detritus treatments: no detritus, low hemlock (62.5 g/m^2), low alder (62.5 g/m^2), low alder (62.5 g/m^2), and high alder (125 g/m^2).

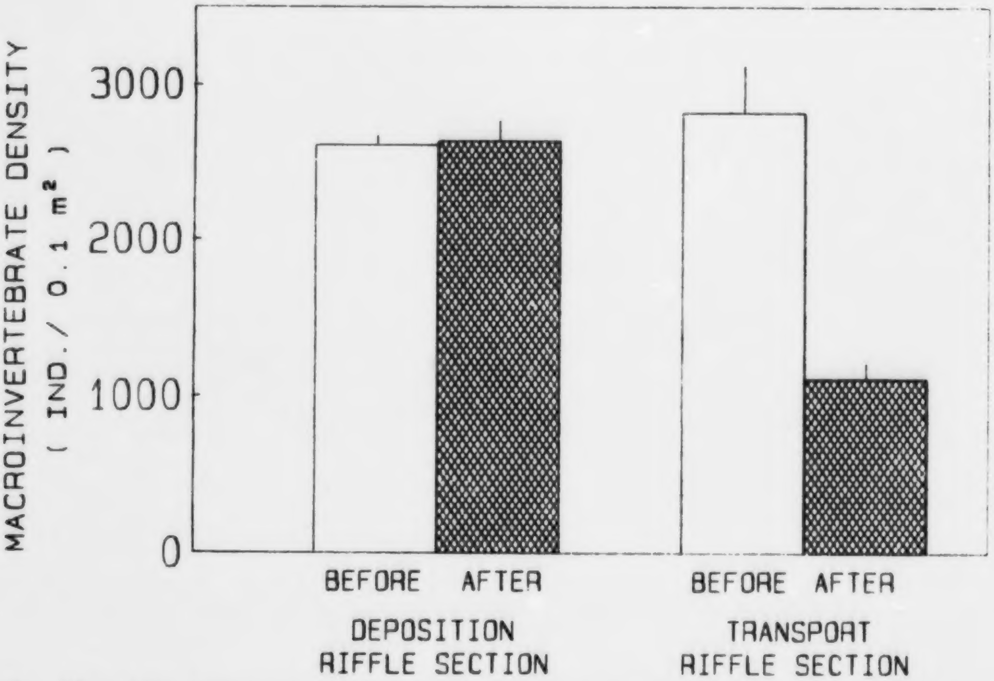

Figure 3. Mean (±SE) macroinvertebrate densities before (white) and after (cross-hatched) sediment additions to riffles where the sediments were deposited or transported by saltation.

physical disturbance that reduced total benthic densities by > 50% in 24 h (Fig. 3) and significantly influenced community composition. Changes in the benthic community were the result of catastrophic drift, and the timing and pattern of the drift increases were related to the vertical distribution of insects within the substrate (Culp et al 1986). Sediment saltation has the potential to act as a community-level disturbance early in the storm hydrograph or at lower discharge magnitudes than required to suspend sediments. Since clearcuttig without buffer zones increased streambank erosion and the input of fine sediments, the impact of saltation on the benthos would be greater after clearcut logging, particularly in the winter when discharge fluctuates frequently.

CONCLUSION AND RECOMMENDATIONS

The Carnation Creek investigation establishes that clearcutting without adherence to the P1 clause decreases benthic densities primarily because of the increased input of fine sediments from eroded streambanks without buffer zones. Detrimental effects of these fine sediments varied between scouring of the substrate in the winter to intrusion into the substrate during the summer. Short-term (24 h) sediment additions further indicated that sediment saltation is a significant mechanism by which macroinvertebrates are scoured from the substrate, and that sediment saltation reduces macroinvertebrate densities.

Post-logging decreases in macroinvertebrate density were not completely prevented by the presence of a <10 m wide buffer zone and natural debris dams, but the detrimental effects were less pronounced. In the buffer zone, the effects of winter scouring on macroinvertebrates were reduced, and in the summer allochthonous litter from the riparian vegetation provided a greater amount of food for macroinvertebrate detritivores, compared to the reach with a clearcut streambank. Manipulative experiments demonstrated that, in Carnation Creek and likely other similar coastal streams, detritus quality and quantity have a greater effect on macroinvertebrate distribution than does substrate particle size.

It is important that buffer zones and natural debris dams be left along coastal streams, and that the buffer zone is wide enough to provide the normal pre-logging levels of allochthonous litter input. However, it is beyond the scope of this study to indicate the optimal buffer strip width for coastal streams, though it is clear that logging with the P1 clause in effect prevents streambank destabilization by leaving a < 10 m buffer zone. Furthermore, the effectiveness of a < 10 m buffer zone in preventing logging-related impacts to the stream would probably be increased if selective logging of merchantable timber in this zone were prohibited, as logging in the buffer zone greatly reduces leaf litter input to the stream.

Because the streambank of coastal streams provides important energy subsidies to macroinvertebrate communities and mediates sediment inputs to the stream, logging of the streambank in coastal streams like Carnation Creek is detrimental to macroinvertebrates. Clearly, as salmonid fry utilize macroinvertebrates as a food resource, management guidelines must protect the streambank interface with the forest if coastal streams are to be maintained as productive salmon fry habitat.

LITERATURE CITED

Culp, J.M. and R.W. Davies. 1982. Effect of substrate and detritus manipulation on macroinvertebrate density and biomass: Implications for forest clearcutting. In: G.F. Hartman [Ed.]. Proceedings of the Carnation Creek Workshop, a 10-year review. Pacific Biological Station, Nanaimo, British Columbia. 404 p.

Culp, J.M. and R.W. Davies. 1983. An assessment of the effect of streambank clearcutting on macroinvertebrate communities in a managed watershed. Can. Tech. Rep. Fish. Aquat. Sci. No. 1208. 115p.

Culp, J.M. and Davies. 1985. Responses of benthic macroinvertebrate species to manipulation of interstitial detritus in Carnation Creek, British Columbia. Can. J. Fish. Aquat. Sci. 42:139-146.

Culp, J.M., S.J. Walde, and R.W. Davies. 1983. Relative importance of substrate particle size and detritus to stream benthic macroinvertebrate distribution. Can. J. Fish. Aquat. Sci. 40:1568-1574.

Culp, J.M., F.J. Wrona, and R.W. Davies. 1986. Response of stream benthos and drift to fine sediment deposition versus transport. Can. J.

Zool. 64:1345-1351.

Gibbons, D.R. and E.O. Salo. 1973. An annotated bibliography of the effects of logging on fish of the Western United States and Canada. U.S.D.A. For. Serv. Gen. Tech. Rep. PNW-10. 145 p.

MacMillan Bloedel Limited. 1979. Logging operations in Carnation Creek 1975-1978. Fish. Mar. Serv. Data Rep. 157. 22 p.

Shortreed, K.S. and J.G. Stockner. 1983. Periphyton biomass and species composition in a coastal rainforest stream in B.C.: Effects of environmental changes caused by logging. Can. J. Fish. Aquat. Sci. 40:1887-1895.

Toews, D.A.A. and M.K. Moore. 1982. The effects of streamside logging on large organic debris on Carnation Creek, B.C. Ministry For. Land Manage. Rep. No. 11. 29 p.

SOME IMPLICATIONS OF VEGETATIVE CHANGES INDUCED BY FOREST MANAGEMENT

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OLD-GROWTH VEGETATION COMMUNITIES

Vegetation was mapped in 1972-1974 by Oswald (1973, 1974) using conventional, panchromatic aerial photographs, ground traverses and plots. Larger scale mapping was done of streamside communities (Oswald 1975) using low-level, 70-mm, color photography, in addition to conventional aerial photography and ground traverses.

Results: Five major associations and three subassociations were described by Oswald (1983) for non-riparian (upland) terrain. These reflected major differences in moisture regime though correlations between mapped soil and vegetation type boundaries were not high. Chief tree species were western hemlock (*Tsuga heterophylla*), amabilis fir (*Abies amabilis*) and western red cedar (*Thuja plicata*). Douglas-fir (*Pseudotsuga menziesii*) occurred in dry, ridge-top positions and Sitka spruce (*Picea sitchensis*) was common only near the stream. Riparian communities lacked Douglas-fir and were characterized by a discontinuous fringe and occasional larger patches of red alder (*Alnus rubra*) along the creek edge, scattered broadleaf maple (*Acer macrophyllum*) and a relatively high proportion of Sitka spruce. Stink currant (*Ribes bracteosum*) and dense patches of salmonberry (*Rubus spectabilis*) were also characteristic of the riparian environment.

Implications: Rates and patterns of plant responses to clearcutting and prescribed burning will differ depending on the vegetation community and its associated soil and climatic systems. Attention will be paid to clarifying the effects of site on vegetative responses to forest management in future data analysis.

MAJOR CHANGES IN VEGETATION COVER AND GROUND SURFACE RESULTING FROM FORESTRY OPERATIONS.

Information was collected at 1431 points spaced 3-m apart along transects located in 7 cutblocks. Transects were run in old-growth stands and rerun to obtain data for 3 years after logging and after prescribed burning.

Results: Old-growth stands had total vegetative cover of 80-90% composed of overlapping tree, shrub and herb and moss layers (Fig. 1). Clearcutting virtually eliminated the tree layer and reduced total cover to an average of 24%. This increased to 36% by 3 years after logging. Burning reduced cover to an average of 5% increasing to 27% 3 years after burning (Fig. 1). In regards to soil erodibility, reduced vegetative cover and increased mineral soil exposure caused by the logging operation was at least partially compensated for by a 50% cover of logging slash. No increase in surface soil erosion was noted. Fall prescribed burning, however, not only reduced vegetative cover but also increased mineral soil exposure by duff consumption and reduced slash cover to less than 15%. The result was increased overland flow and surface soil erosion the first winter after the burn (Fig. 2), particularly on steeply sloping segments.

Implications: Reduced vegetative cover and increased soil disturbance associated with felling and

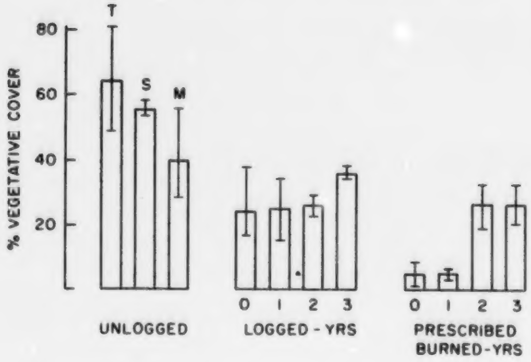

Figure 1. Average and range of vegetative cover as a percentage of the area of surveyed cutblocks for 9 stages of development. Numbers for logged and prescribed burn stages represent years since logging or burning. In the unlogged stage, T = Tree layer; S = Shrub and herb layer; M = Moss, liverwort and lichen layer.

yarding at Carnation Creek has not likely increased sediment input to streams. Prescribed burning, however, can trigger overland flow on steep slopes and create a potential for transfer of sediments. In these situations, lighter (spring) burns may be more appropriate. Reduced vegetative cover alone can also result in:

- Reduced evapotranspiration and higher summer water tables in the valley bottom (Hetherington 1983).
- Reduced soil strength and thus reduced soil stability resulting from tree root decay following felling (Sidle et al. 1985). Affects upland slopes and streambanks.
- Increased water temperature (Holtby and Newcombe 1983).
- Reduced leaf litter input to streams (Culp and Davies 1983).

3. RATE AND PATTERN OF VEGETATIVE RECOVERY.

In 1978, the CFS established a study (PC-76-02) to monitor revegetation following logging and burning. Permanent plots were located systematically along predetermined cross -sectional transects in 11 logging settings. Revegetation assessments have continued to date in accordance with King & Oswald's (1983) sampling schedule. Some plots will have 10 years measurement by 1987; all 260 plots will have at least 10 years of records by 1991. The vegetation database represents a unique inventory spanning 10 years in an operational setting.

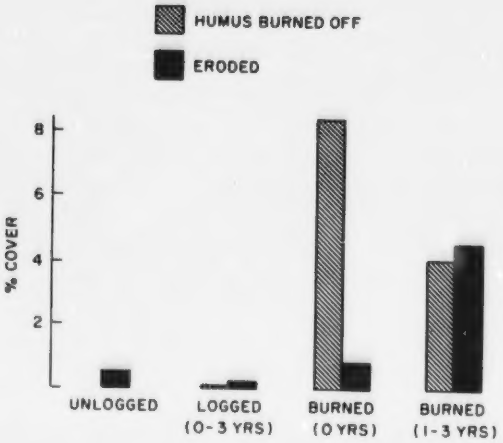

Figure 2. Percentage cover of eroded and humus-burned-off ground surface conditions for unlogged, logged and burned cutblocks.

Results (an example): In Subunit 1 (RR 8-floodplain), dominant plant species in the 3rd year assessment were *Alnus rubra*, *Rubus spectabilis*, *Polystichum munitum*, *Athyrium filix-femina*, and *Epilobium angustifolium* (Table 1). By the 5th year, *Alnus rubra*, *Rubus spectabilis* and *Polystichum munitum* had reached maximum frequencies but continued to add to their respective heights. However, rate of overall increase in *Alnus rubra* and *Rubus spectabilis* had slowed approximately 2.7 and 2.1 times, respectively (Fig. 3). *Epilobium angustifolium* was relatively constant in all parameters. *Athyrium filix-femina* was absent from 5th year assessments (Table 1). These plots were aerially treated with glyphosate the following year (1984).

Implications: Revegetation of logged and burned sites by *A. rubra* and *R. spectabilis* inhibits successful establishment and growth of crop trees in the CWHb1[1] 1/ biogeoclimatic variant. On these

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[1] Windward Submontane Maritime Wetter Coastal Western Hemlock.

Table 1. Subunit 1, Floodplain Wetland. Sample size = 7 plots, 28 quadrats. Burn success = 8% of quadrats burned, average intensity low.

Tree species	Frequency %				Avg. Height (cm)			
	78	79	80	82	78	79	80	82
Thuja plicata	32.0	17.8	17.8	35.7	23	49	79	148
Tsuga heterophylla	7.1	0	0	0	30	0	0	0
Alnus rubra	0	3.5	7.1	10.7	0	91	220	394
Picea sitchensis	0	0	0	3.5	0	0	0	45
Seedlings (all spp.)	0	0	3.5	0	0	0	2	0

Shrub species	Frequency %				Cover %				Modal Height Class			
	78	79	80	82	78	79	80	82	78	79	80	82
Rubus spectabilis	57.1	67.8	75.0	92.8	11.9	15.8	26.9	43.4	4	5	5	6
Ribes bracteosum	32.1	17.8	17.8	25.0	5.6	4.5	12.6	6.4	5	6	6	5
Sambucus racemosa	25.0	32.1	25.0	25.0	1.1	4.4	7.8	4.2	3	5	6	6
Gaultheria shallon	17.9	3.5	3.5	10.7	3.3	< 1	< 1	1.3	5	2	4	4
Vaccinium ovalifolium	10.7	3.5	< 1	0	< 1	< 1	< 1	0	4	2	4	0
Vaccinium parvifolium	3.5	3.5	0	10.7	< 1	< 1	0	< 1	3	3	0	4
Rubus parviflorus	0	0	3.5	14.2	0	0	< 1	5.4	0	0	5	6
Rubus leucodermis	0	0	3.5	0	0	0	< 1	0	0	0	5	0
Aruncus sylvester	0	0	0	28.5	0	0	0	2.4	0	0	0	5

Forbs & Moss Species	Frequency %				Cover %			
	78	79	80	82	78	79	80	82
Polystichum munitum	60.7	25.0	53.5	67.9	11.2	3.1	11.7	16.9
Galium boreale	39.3	60.7	35.7	42.9	5.3	5.6	2.7	1.0
Tiarella trifoliata	35.7	24.1	28.5	10.7	2.0	< 1	1.7	< 1
Blechnum spicant	32.1	53.5	25.0	25.0	2.9	9.7	3.0	3.2
Grass spp.	21.4	21.4	28.5	25.0	< 1	1.0	2.2	< 1
Hylocomium splendens	17.9	0	0	0	3.3	0	0	0
Athyrium filix-femina	17.9	17.8	28.5	0	1.3	< 1	4.6	0
Maianthemum dilatatum	17.9	28.5	17.8	28.6	1.1	2.2	1.5	4.2
Montia sibirica	14.3	3.5	3.5	10.7	1.0	< 1	< 1	< 1
Epilobium angustifolium	17.9	71.4	35.7	39.3	< 1	5.3	2.6	2.5
Tolmia menziesii	10.7	10.7	10.7	0	< 1	< 1	3.9	0
Circea alpina	7.1	14.2	0	7.1	3.2	4.1	0	< 1
Luzula spp.	7.1	3.5	3.5	3.5	< 1	< 1	< 1	< 1
Mitella pentandra	7.1	10.7	3.5	0	< 1	< 1	< 1	0
Viola glabella	3.5	0	0	0	< 1	0	0	0
Anaphalis margaritacea	0	0	10.7	25.0	0	0	< 1	3.1
Pteridium aquilinum	0	7.1	7.1	32.1	0	1.2	< 1	4.6

sites, inspection for planting prescriptions should be conducted before harvesting, with detailed inspections immediately following actual site preparation. Major competing species present and potential competitors, stock type, site history and site factors, primarily climatope, hygrotope and trophotope, should be identified at this time. Any subsequent brushing and weeding that is performed should be based on a revegetation and site inventory.

For the type of riparian community occupying the poorly burned floodplain described as Subunit 1 (Oswald 1983), planting should occur in the 1st year. Beyond the 3rd measurement year, continued development of major competitors will reduce regeneration establishment and growth. By the 5th year, initial stabilization in the height of major competitors has occurred except in alder (Fig. 3). But, further increases in foliage density have resulted in progressive canopy closure, particularly in salmonberry. Brushing and weeding in the 3rd year should enhance regeneration success by decreasing *A. rubra* competition in the tree layer and *R. spectabilis* in the shrub layer.The 10th year of revegetation assessments (3rd year post-herbicide treatment) in Subunit 1 will be conducted in 1987, allowing better definition of revegetation and regeneration trends.

Variability in regeneration success and revegetation patterns are now being investigated to define relationships between species distribution, growth dynamics, site factors and treatment history (Hays 1986a). A set of computer programs was recently developed at PFC (Hays 1986b) to convert the vegetation database into a Statistical Analysis System (SAS)-compatible matrix. Using SAS, multivariate analysis including cluster analysis are

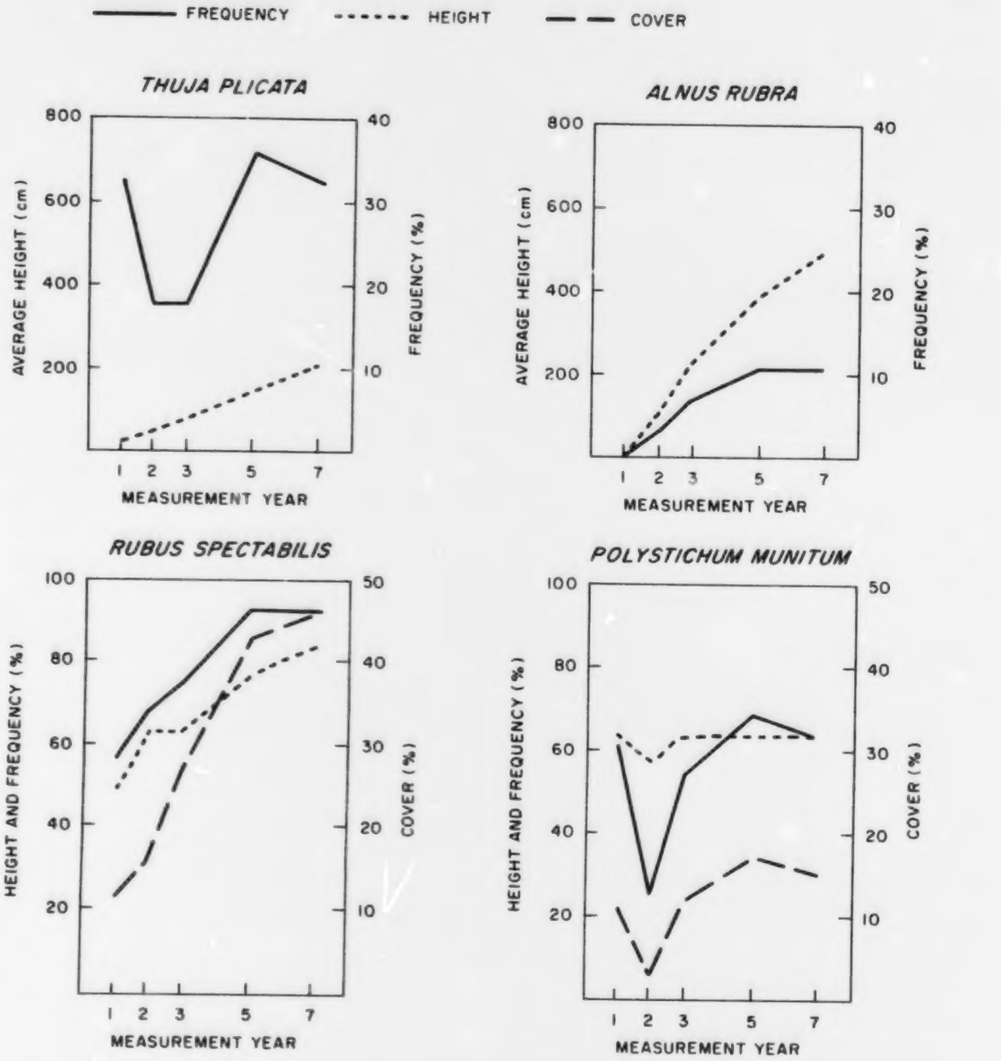

Figure 3. Frequency and percent cover or height for *Thuja plicata* and dominant competitors, *Alnus rubra, Rubus spectabilis* and *Polystichum munitum* in Subunit 1 (Ritherdon 8-floodplain).

being conducted. These procedures provide a means to graphically visualize those factors (singly or in combination) that are influencing species distribution and overall revegetation patterns. Areas of investigation include:

1. Identification of species-site relationships with reference to site history (defining species distributions),

2. Evaluation of treatment effect(s) on revegetation and regeneration species: a) which treatment(s) are most effective in maximizing yields? (Stock type a potential determinant) b) which treatment(s) are most effective in minimizing 'weed' competitors? (Time factor is important in terms of achieving 'successful' crop tree establishment and release).

Results from analyses that address these objectives will aid in the understanding of revegetation responses to site factors, site preparation, and brushing and weeding practices. Benefits of conducting research in an operational setting such as the Carnation Creek Experimental Watershed accrue to industry, academia, and government. Field foresters and forest managers may, for example, increase their predictability of revegetation patterns in the CWHb, biogeoclimatic subzone by extrapolating from the Carnation Creek example. The scale and precision of vegetation assessments conducted under PC-76-02 reflect its initial objectives, namely to identify revegetation patterns over time, under various environmental conditions. The authors suggest that the current and future additional database has further potential, particularly in combination with concurrent ecological research conducted in the watershed (Hays 1986a).

REFERENCES

Culp, J.M. and R.W. Davies. 1983. Effect of substrate and detritus manipulation on macroinvertebrate density and biomass implications for forest clearcutting, p. 210-216. In: G.F. Hartman [Ed.]. Proceedings of the Carnation Creek Workshop, a 10-year review. Pacific Biological Station, Nanaimo, British Columbia. 404 p.

Hays, W. 1986a. Response of secondary vegetation to silvicultural treatment, soil and site conditions in the Carnation Creek Watershed. MSc thesis, Univ. of Victoria. In progress.

Hays, W. 1986b. Supplementary data collection and software development in support of vegetation management at Carnation Creek. FRDA file ref. 6857 6 52-10-3 (4903 2.6): Software documentation. Unpublished.

Hetherington, E.D. 1983. A first look at logging effects on the hydrologic regime of Carnation Creek Experimental Watershed, p. 45-62. In: G.F. Hartman [Ed.]. Proceedings of the Carnation Creek Workshop, a 10-year review. Pacific Biological Station, Nanaimo, British Columbia. 404 p.

Holtby, B. and C.P. Newcombe. 1983. A preliminary analysis of logging-related temperature changes in Carnation Creek, British Columbia, p. 81-99. In: G.F. Hartman [Ed.]. Proceedings of the Carnation Creek Workshop, a 10-year review. Pacific Biological Station, Nanaimo, British Columbia. 404 p.

King, R.K. and E.T. Oswald. 1983. Revegetation of Carnation Creek Watershed, p. 110-128, In: G.F. Hartman [Ed.]. Proceedings of the Carnation Creek Workshop, a 10-year review. Pacific Biological Station, Nanaimo, British Columbia. 404 p.

Oswald, E.T. 1973. Vegetation and soils of Carnation Creek Watershed (A progress report). Can. For. Serv., Pacif. For. Res. Cent. Int. Rep. BC-43. 38 p.

Oswald, E.T. 1974. Vegetation and soils of Carnation Creek Watershed (Upper section). Can. For. Serv., Pacif. For. Res. Cent. Misc. Rep. BC-P-11-74. 15 p.

Oswald, E.T. 1975. Vegetation of Carnation Creek streambed. Can. For. Serv., Pacif. For. Res. Cent. Misc. Rep. BC-P-12-75. 6 p. + 2 figs.

Oswald, E.T. 1983. Preharvest vegetation and soils of Carnation Creek watershed, p. 17-35. In: G.F. Hartman [Ed.]. Proceedings of the Carnation Creek Workshop, a 10-year review. Pacific Biological Station, Nanaimo, British Columbia. 404 p.

Sidle, R.C., A.J. Pearce and C.L. O'Loughlin. 1985. Hillslope stability and land use. Amer. Geophys. Union, Water Res. Monogr. 11. 140 p.

PANEL DISCUSSION
SESSION 3: THE FOOD CHAIN: STREAM PRODUCTION AND TERRESTRIAL VEGETATION

RESPONSE BY A.D. DELEEUW, MINISTRY OF ENVIRONMENT AND PARKS

Mr. Chairman, speakers and Mr. Levings, I would like first of all to thank the program coordinator for requesting of me to critique the papers of this session vis-a-vis my dealings and workings in the real world. Before I make my specific comments, I will include just a few general remarks on my interactions with Charlotte streams.

My involvement with logging and fish streams of the Queen Charlotte Islands over the past four and a half years has been associated primarily with recommendations to the Ministry of Forests within the referral system. These recommendations include changes in, or acceptance of, road and cutblock development strategies within drainage basins of 5 year plans, and alterations to falling and yarding patterns and/or boundary changes on specific cutblocks at the cutting permit stage.

I can do nothing about whether logging does or does not take place, society has decided that for us. My perception of the real world therefore is; within the framework of forest harvesting, to minimize, through clear and objectively justifiable recommendations, the impact of logging on fish habitat. In some site specific cases, this decision making process involves acknowledging the impracticality of applying the working concept of multiple use. We are then forced to opt for either one or the other resource, but not both. These are the simple realities of fisheries and forest management in the field. Ultimately our collective goal is to reap the extensive benefits from timber harvesting while simultaneously (and at times miraculously) maintain the quality of stream ecosystems for optimum fish production.

The vast majority of good fish producing streams on the Charlottes are small, less than 450 km^2, have relatively low to moderate gradients, are large organic debris structured and nutrient poor. Small to medium sized gravels are generally abundant, temperatures are moderate to cool, and large extremes in discharge are the norm. In my opinion, channel bank stabilized large organic debris is by far the most important factor responsible for fish production in Charlotte streams. Large organic debris is the meat and potatoes so to speak (or the bread and butter if you're a vegetarian) of good salmon and trout runs in the Charlottes.

It is with the understanding of the forgoing that in addition to gaining a better working knowlegde of the system as a whole, I came here to formulate guidelines from the information presented for improved resolution of fish forestry conflicts.

With respect to Charlotte streams then, when applying the "formulation of guidelines critique" to the Carnation Creek water chemistry results presented by Charles Scrivener and the primary production work discussed by John Stockner, I therefore formulate the following question: Is the rate and/or percentage of forest harvesting on a per unit of catchment area basis really in the long term going to make a difference to nutrient concentrations, algal growth and ultimately fish production if phosphates are the primary limiting factor in many of our coastal streams? If it does not, in a readily quantifiable and obvious manner, then no recommendations can be made or are required in terms of forest harvesting rates or logging technologies that will mitigate in the area of nutrients or algal growth effects in stream ecosystems. This is especially true if other impacts on fish populations such as long term changes in stream channel morphology and hydraulic regimes completely eclipse the effects of logging on changes in stream nutrient concentrations.

The information on macroinvertebrates presented by Mr. Culp has some very real implications to Charlotte streams. I will not elaborate here on the virtues of the P. 1 clause, since the yarding of timber through streams in almost all cases is avoided by additional road construction, directional falling and yarding recommendations at the cutting permit stage. Like Carnation Creek, the primary energy source of Charlotte streams is leaf litter detritus, with alder being the predominant and in many cases the only decidious species. The conflict which frequently arises on the Charlottes is between silvicultural and fisheries concerns along streams. Alder removal projects, such as conifer release and/or alder seed control, often conflict with maintenance of alder for bank stability and leaf litter input. The situations is extremely complex due to the vast number of very small tributaries, sidechannels and rearing ponds associated with Charlotte streams. What I would like to see, is some sort of alder control guideline which relates decidious (in my case alder) buffer zone dimensions to stream channel width, rather than ad hoc recommendations based largely on educated intuition and the knowledge that detritus is a fundamental component to Charlotte streams. In addition to silviculture, the removal of streamside alder is also often a necessity to back spar trail construction to facilitate grapple yarding operations. From a fisheries perspective we need alder, just exactly how much and where is the question.

The aspects of detrital input and post logging revegetation of alder has further fisheries implications over the long term. Is there an optimum age of alder for leaf litter input and bank stability capabilities? Is it possible to develop an alder age structure management strategy that can accomodate both silvicultural and fisheries concerns? I agree with Messrs. Smith, King, and Ms. Hay, that conducting revegetation research in an operational setting has benefits, and should in my opinion, address silvicultural concerns along streams with a view to provide dimensions of alder leave strip widths for different types and sizes of streams.

In all the above comments I have placed a greater emphasis on maintaining stream sturcture such as continued input and management of LOD, stream bank stability and alder buffer zones than I have on other issues. I have done so intentionally since as I stated earlier, I believe stream structure to be the most important aspect of Charlotte streams.

If I were to suggest yet another candidate for research relative to the fish forestry issue, it would have to include the determination of optimum tree size or wind firm buffer zone widths to be left along streams for the continued natural input of large organic debris to Charlotte streams. Does large mature spruce, say in the 4 to 8 feet butt diameter range, play the same role in the composition of stable LOD on small streams as it does on larger systems? Is there a relationship between tree diameter size and its ability to be stable within differing stream channel widths, and can this be managed over the long term?

Thank you for listening to my comments.

RESPONSE BY JOHN LAMB,
DEPT. OF FISHERIES AND OCEANS

INTRODUCTION

During 14 years of wrestling with the concept of Integrated Resource Management (I.R.M.--for the initiated) I have sat across the table or walked the bush with most of the forestry people in this room. In addition, I have received character building criticism from many of the conservatively minded ladies and gentlemen here today. Tom Chamberlin asked me to remain within my area of expertise during this panel discussion; however, I had difficulty in deciding what kind of expertise I qualified for, given this kind of experience and training. I decided that I was qualified to speak candidly on some field applications of the four research papers, and relate some of my personal experiences.

I have heard comments at the same time that I.R.M. is a legalized form of extortion whereby a fisheries agency may coerce protective or enhancement measures for fish habitat by the implied--but yet to be seen--destruction of the fisheries resource. On the other hand, my contacts with the conservatively minded elements would lead me to believe that fish habitat is collectively 'going to hell in a motor-cart'.

The bridge in these positions is a knowledge of the process which may result in impacts on either resource and a mutual understanding of the interests of our common resources. For these reasons I view the type of applied research in Carnation Creek as an integral part of I.R.M.

SPECIFIC COMMENTS

The brevity or levity of these comments are not intended to reflect any lack of importance attached to the research.

Water Chemistry:

Well, Charlie, you have certainly alleviated the fear that the carcasses of fish would fill the estuaries following logging--their gills clogged with excess ions.

Certainly the determination of a non-concern is an important as any critical finding. Understanding the processes of water chmistry in natural and logged drainages will have further applications as has already been demonstrated in Stockner and Shortreed's work on autotrophic communities.

Autotrophic Production:

I viewed this paper as supportive of much of our existing practices in prescribing protective measures of fish habitat. The maintenance of gravel quality and minimization of erosion products to the stream has long been an objective of stream protection measures. It was interesting to note the importance of timing and severity of freshet events in determining the period of autotrophic production and, in the following paper, of macroinvertebrate production.

The work seems to destroy the long held assumption that increased light and temperature would benefically affect primary production.

One day, we may be able to enter in co-operative joint fertilization projects with forestry programs to introduce phosphorous into selected stream systems.

Macroinvertebrates:

This study suggests that we re-think our definition and application of streamside buffers. It raises questions regarding situations such as:

- reaches where deciduous trees are absent.
- reaches where windthrow concerns may be overriding.
- increased deciduous growth in streamside reaches following selective logging.

We may have to be more precise in our definition of buffer strips to include composition and density and increase the emphasis on their protection during all phases of logging, including post-logging silvicultural treatments.

Again, it was interesting to note the importance placed on hydrological regime in the production of macroinvertebrates.

We should bear in mind that logging is currently ongoing in the Carnation Creek drainage. Logging is active in the steep, unstable areas above E weir and future applications will be made for C tributary. The current rate of 41% harvest will probably exceed 80% by the time first pass logging is complete in the Carnation Creek drainage. This higher elevation logging has a greater potential for affecting the hydrologic regime and further aggravating stability of the slopes immediately above the channel. I would suggest that we are far from writing the final chapter on the condition of this drainage.

Vegetative Changes Inducted by Forest Harvesting:

The substantial increase in surface erosion following burning suggests that burn sites near streams should be more closely controlled. On critical stream reaches, some foresters are employing sprinklers and controlled burns with some success.

Also, the reduced streamside canopy following burning and other silvicultural treatments near streams would result in a loss of detrital inputs for macroinvertebrate production and future L.O.D. The change in riparian species mix to the less desirable conifers would reduce stream productivity.

CLOSING

In closing, these papers collectively support my contention that the critical importance of the streamside zone to stream productivity gives limited opportunity for trade-off type decisions near the stream. As fisheries resource managers we must apply an increasingly restrictive definition of integrated resource management as planning areas approach the streamside zone.

Transposing study results into field practices is a difficult process, and often inconsistently applied. The ultimate responsibility for completing that process rests with the lowest planning/operational level. I hope that in the ensuing discussions that we are able to grapple with some of the problems and conlficts which will be faced by the operational level in implementing these study results.

RESPONSE BY JACK DRYBURG,
MACMILLAN BLOEDEL

How do the preceeding presentations on Stream Production and Terrestrial Vegetation relate to what is or could be going on in the real world of Forestry and Fisheries? I am going to try to give some insight from an operating Forester's viewpoint, as coloured by more than 10 years of direct involvement with the Carnation Creek Project.

BUFFER ZONE MANAGEMENT

Of utmost importance is the concept of active management of the streamside vegetation zone. From the papers today and yesterday, there can be no doubt that their role in streambank protection and provision of food sources and habitat is not a small one. Naturally, foresters and logges do not like to see timber "lost" in buffer zones or forest land left idle; nor do fisheries personnel like to see their resources depleted.

It has been suggested that buffer zones be increased beyond the current 10 meter zone in order to maintain the "normal" prelogging levels of leaf litter and insect components of the food chain. As the limiting factor within Carnation Creek for coho is the availability of overwintering habitat, I question the idea of expanding the buffer zone, at high cost, to maintain a non-limiting factor.

Currently, buffer zones are being left along streams after site specific review with the resource agencies. Within this zone, the following things are partially being done or could be done in relation to the research presented:

a. Leaving smaller coniferous trees intact as a source of leaf litter input, and as a future source of large organic debris input into the stream when they blow down. (intentional planning, not just accidental)

b. Leaving selected large conifers leaning towards the stream, as a source of leaf litter and an immediate future source of large organic debris when they blow down. (again intentional, not just accidental)

c. Using normal or directional falling techniques and carefully removing those large trees not of significant value for provision of large organic debris, bank stability or litter input. (If not removed, blow down freequently puts them on the ground to rot - with no significant benefit to either resource, as readily seen at Carnation Creek).

d. Retaining mature alder trees in the buffer zone adjacent to recently- harvested land, in those situations where alder trees are necessary for streambank protection and productivity. (And where these alder trees are retained, recognition must be made for the necessity of alder treatment, usually herbicides, in the adjacent land up to the buffer zone).

e. Eliminating the requirement for buffer zones of larger trees around smaller stream channels where bank stability is not a problem and deciduous leaf litter input can be provided by alternate rapid growing species, such as salmon berry.

SLASHBURNING

Much criticism has been aimed at the forest industry and Forest Service in recent years, for aesthetic as well as, in many cases, perceived environmental reasons. Therefore, it is encouraging to see research that indicates no significant detrimental effects on the Carnation Creek stream system as a result of slashburning. Specifically nutrient releases into the stream resulting from burning were short-lived and not harmful. And, although mineral soil exposure, overland flow and soil displacement increased, no signficant impacts were transmitted to the creek. This means that slashburning is a valuable silvicultural tool to manage brush, slash and pests and to reforest areas, and must be used wisely.

REVEGETATION

The revegetation research is of keen interest to foresters, with one practical application being to help refine pre and post logging silvicultural prescriptions within site types of that particular biogeoclimatic subzone. Much of the research substantiates what is currently being practiced.

Another potential pplication is the utilization of data on the stabilization of frequency and height of brush species on a site to help determine the optimal time for brush treatment to release conifers from competition.

FOREST AND STREAM FERTILIZATION

It has been identified that after logging, the algal portion of the food chain within Carnation Creek did not increase as expected, due to a limiting factor - a shortage of phosphorus, and therefore stream fertilization be considered in similar water bodies.

At the present time, the forest fertilization program in British Columbia is expanding. I suggest there are opportunities for forest and fisheries resource managers to investigate and to cooperate in joint fertilization programs in specific areas, including possibilities of treating forest and stream at one time with a predetermined fertilizer mix. (i.e., Cross stream fertilization)

COOPERATION

The previous example of joint fertilizer program may be considered a pipe dream to some, but what I really want to convey is the concept of Fisheries-Forestry cooperation that is needed to make any application of Carnation Creek Research actually work in the real world. I have seen this attitude of cooperation work between fisheries researchers and loggers at Carnation Creek as they began to learn and appreciate each others resource concerns. My hope is that this spirit can be continued in the practical application of the research from Carnation Creek.

QUESTIONS
SESSION 3: THE FOOD CHAIN: STREAM PRODUCTION AND TERRESTRIAL VEGETATION

Moderator: C. Levings

MR. POULIN: Vince Poulin. This is really going to just echo Dionys' comments. It was a question that came up in Joe Culp's presentation.

Again as Dionys indicated, his reason for electing certain prescriptions along streams regarding streamside alder was primarily stability, but for you, Joe, your data did show that leaf litter did reduce as a function of clear cutting along stream edges and also invertebrates density did decline. Yet later on this afternoon we're going to find out that coho size during summer increased, cutthroat size has increased, steelhead zero plus and one plus fish size has also increased.

We know, as Dionys indicated, many thousands if not millions of dollars are spent with silvicultural treatments along streams as the foresters allege from streamside alder.

My question to you is that given the results of the fish growth information which tend to be somewhat independent of leaf litter inputs, does that weaken our argument as biologists that leaf litter inputs in streams are necessary?

MR. CULP: I wish you hadn't asked that question actually, because that's probably one of the toughest questions that could be asked.

MR. POULIN: I'm getting trained at this, because I get put on the same spot.

MR. CULP: The problem is there are a number of variables, as you know. One of them that we're not discussing is was there more habitat, more territories available, for example, for coho after logging immediately the first two or three years? I can't answer that. Maybe Blair Holtby or someone else can discuss that this afternoon. My comments were basically from the point of view of invertebrates. I wasn't trying to make the connection because I didn't in my studies with coho. Perhaps Gordon or somebody else can, or Charlie could do that this afternoon. I think your point is valid. I think we have to make much more concerted efforts to link the macroinvertebrate data, the leaf litter data, and the production of coho. But there's a number of compounding variables. Temperature is another one which hasn't been discussed yet.

So I'm not answering your question, I'm waffling around. I don't have an answer to your question, I don't think anyone here can.

MR. SCRIVENER: I think Blair will answer basically that question on why the coho are the larger in size. It's more to do with the temperature effects and not with any growth as a result of changes in the food resources.

MR. MORRISON: Doug Morrison. I'm wondering with the amount of vegetation regeneration studies that have gone on and given that in the intensive treatment area the alder, streamside alder, was pretreated prior to logging and in the careful treatment area the alder, streamside alder, was also treated, I'm wondering if the vegetation studies have indicated any response to that pretreatment or treatment of streamside alder in terms of alder inseeding on the high sites adjacent to those treatment areas in terms of numbers of alder per unit.

MR. DRYBURG: I'll just give it from just a visual viewpoint and not from a specific research viewpoint, if I may, Doug.

First of all, you are referring between the "intensive treatment" and the "leave strip treatment", are you?

MR. MORRISON: No, the intensive treatment and the upper one, the careful treatment area where the alder was also treated.

MR. DRYBURG: Oh, okay, I was thinking of the other, but basically I don't think you will find a heck of a lot of difference between the two. Any difference is probably due to to the timing more than anything else, I would suspect.

MR. MORRISON: Maybe my question is not yet clear. Compare those two areas where the alder, streamside alder, was treated to the leave strip area where the alder was not treated, and have we found that, in fact, by treating streamside alder we reduce the alder inseeding problem on the high site of the regenerating area?

MR. DRYBURG: Generally, yes, you can see the difference, but again there are other complicating factors, and you can't say definitely because of the method of site preparation: scarification of burning versus no treatment, and that complicates it all. And I would say it would be very, very difficult to come up with a definite answer. Some of the individual plots, vegetation plots, put in in some of those sites may give some general indications.

MS. HAYES: I think it's important to note that because of all the different types of variables we're assessing there, it's not only what's regenerating. We're also looking at different site parameters and really you need to do a multi-varied analysis to find what has actually grown there and why and that's based again on the site history; for example, taking into consideration all the different treatments. So until that can be done, really you can't pinpoint anything at this stage.

MR. SMITH: Just extrapolating a bit up to the Charlottes. It's readily evident there how the colonization of alder depends very much on the level of disturbance and maybe somewhat less on seed source. Obviously there's going to be a seed source there somewhere, but in the old growth stands in the Charlottes, the alder is restricted to the creeks or the rivers right along the banks. Once logging takes place, it starts moving into the upland areas up the slope somewhat. Probably the amount related to the amount of yarding disturbance in those areas and on things like bedrock type and so on and chemical composition in the soil.

And then with landslides, the alder moves even further up the slopes, and this occurs over a fairly long period of time.

In other words, as the lower part of the slides are colonized with alder, they become seed bearing, and it slowly moves up. And I think what I'm trying to say is the amount of alder is related very much to the ground conditions and maybe somewhat less to the actual proximity of seed alder trees.

MR. CAIRN: Chris Cairn. I just have a couple of comments regarding stream and forest fertilization, because a considerable amount of interest has been expressed about that.

One of the first things I should mention is there has been a considerable amount of work done on stream fertilization as well as the lake fertilization work that John has talked about, and it started in I98I as pilot studies on Vancouver Island.

And it should be of interest that through that study, in fact, organic matter treatments in addition to inorganic fertilization treatments were, in fact, compared both in terms of looking at invertebrate responses as well as fish responses, and it was found at that time that, in fact, the inorganic treatments resulted in higher growth rates and higher overall productivity than the organic matter treatments, and that may lend some help in terms of the previous question by Vince.

The other point I wanted to make is there has been interest in talking about combined forest and stream fertilization, and I should mention that I've been involved in some of this work in the past, and it's clear if this is to proceed there really has to be an acute consideration of the timing.

Forest fertilization, of course, takes place mainly in the fall months, and at that time as John as mentioned there is considerable problem with very high flushing rates which tend to remove the periphyton activities in some of the streams of interest. And if, in fact, phosphorus is included in the forest treatment at that time with the intent of only treating the aquatic system, there's a problem of complete flush-through of the phosphorus through the system, and it may not be of very much use in terms of trophic production.

Now, that's not to say it may not be of use in terms of phosphorus being added for forest productivity, which it is apparently a problem on the North Island, for example.

So I thought it important to just make a few of these comments in the light that there is so much interest in the combined treatment effect for both aquatic and forest fertilization and the fact that there are studies ongoing, not only the pilot study in 1981 in stream fertilization, but there is whole river fertilization studies ongoing on the North Island right now, and some of that work is being published in some of the primary literature.

MR. DRYBURG: I talked about the joint fertilization as a opportunity of cooperation, but you're mentioning the phosphorus is essentially needed in the springtime for algal growth, in essence. That's one thing you're mentioning?

MR. CAIRN: Yes, the important time is certainly in the spring, that's when the primary bloom for spring productivity happens.

MR. DRYBURG: We have a lot of researchers both in universities and government agencies, dealing with inorganic chemistry and whatever else, and we have all kinds of opportunities to develop slow-release fertilizers, and I am quite sure here is an opportunity to develop a slow-release phosphate that could last two or three years and therefore be available during that prime spring period.

MR. CAIRN: Sure. We've actually looked at some of those slow- release fertilizers on the North Island studies, and there is a possibility of them being useful.

MR. DE LEEUW: Dionys de Leeuw. I take a rather dim view of the whole business of fertilization, and the reason is is that I'm not all that up on the recent literature, but I read a paper a few years ago by Dr. Mason where he artificially fed coho fry in the stream and had a control section where he did not do that.

He fed them throughout the entire summer, late fall period. Then he monitored smolt output from those reaches, and compared the actual number of smolt of the control section as opposed to that section and found no difference. And the implication was that the characteristics of the stream, in fact, determined the number of smolts that the stream reach produced rather than the food source. You may, in fact, have lots of food in one stream, but unless you have that availability of overwintering habitat within those systems, you're literally wasting your time.

MR. CAIRN: Yes, I'm aware of that study. The problem was in that particular study he had an extreme limitation of overwintering habitat.

Recently the studies from the North Island have shown that, in fact, we do realize 30 percent gain in steelhead smolt yield in a much larger system like the Keough River in which we're talking about 32 kilometers of river land over a 100 square kilometer watershed. The Keough River is, in fact, much more complex in both rearing and overwintering habitat than the stream that Mason was using, and the results are very different.

MR. HAIGER: Chris Haiger, Ministry of Forest and Lands, and this question isn't for Doug Morrison either.

But going back to the stream bank vegetation and trying to do something as John suggests in terms of jointly managing that detrital input, I'd like to ask Joe Culp if there's enough information from his earliest samples in the leave strips to characterize that by species; and, secondly, if you couple that with Wynne's information now, could we undertake some sort of a study to compare perhaps the initial contribution and then monitor over time with the change in the vegetation what species are contributing to the detritus in the stream?

MR. CULP: You mean species of trees?

MR. HAIGER: Species of vegetation.

MR. CULP: Certainly the information is there, the prelogging, because Phil Neaves did a very extensive study looking at many areas along the creek, the actual composition. He's got it partitioned into species specific components. So the data I collected post logging was simply looking at total amounts of leaf litter input, so that information is not clear, although I'm not aware it there are any other studies in B.C. where you could get that.

Surely someone could begin estimates of that, but the prelogging information is there. You could go up now and do a post logging type study. That's about all I can add to that.

MS. HAYES: Just regarding that, the number and type of plots that we have along the streamside are relatively less than might be desirable for statistically significant results to be deduced for, say, developing some guidelines for a strip.

So I was just commenting to Dick that there are plots that have been assessed along the stream bank; however, the number is down. There are back channels and the like that would suffice, for plots along back channels. But for the most part we are looking at the flood plain.

MR. YOUNG: Thank you too, Colin, for your job as moderator.

I know as a convenor I'm not supposed to say anything, but, in fact, I just wrote a letter to my two friendly fishery buddies in the two agencies. I'm particularly interested in discussion about integrating forestry and fisheries fertilization.

About seven or eight years ago I approached both fisheries agencies and said surely if there's a fertilizer mix - this is in the old Hayward days - with the potential of integrating operationals, that should be easily done, if here's the potential there. And I was turned off, and they said it is not desirable to do that.

And maybe the discussion coming up at the latter part of the morning here has indicated that, but surely if it's desirable, then surely there's nothing insurmountable to integrate forest and fisheries fertilization programs, be it in the mix of the fertilizer or the integration of the programs.

SESSION 4:
REARING HABITAT

Moderator: Dr. T.G. Northcote
University of British Columbia

WINTER ECOLOGY OF JUVENILE COHO SALMON IN CARNATION CREEK: SUMMARY OF FINDINGS AND MANAGEMENT IMPLICATIONS

Tom G. Brown
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INTRODUCTION

The winter ecology of juvenile salmonids in Carnation Creek has been studied previously by Bustard and Narver (1975a) and Tschaplinski and Hartman (1983). They reported that juvenile coho (*Oncorhynchus kisutch*) undergo a distinct shift in distribution and habitat use during the fall. They stressed that high mortality can occur during the winter period and stable over-wintering habitat, in the form of either main-channel debris jams or off-channel swamps and tributaries, is essential for over-winter survival.

In this paper, we summarize more recent studies of the winter ecology of juvenile coho in Carnation Creek. These studies have focused on: describing the essential characteristics of main-channel and off-channel winter habitat in more detail; evaluating variation in its importance to smolt production; and further examining the behaviour, movements, and growth of juvenile coho over the winter period. We will also discuss the relevance of these findings to resource managers.

METHODS

Habitat utilization and movements of coho in the fall and winter period were monitored by underwater observations of fish in the main-channel (Tschaplinski and Hartman 1983), by use of small fish fences at the outlets of small tributaries (Bustard and Narver 1975a; Tschaplinski and Hartman 1983; Brown 1985) and by wire mesh minnow traps (Brown 1985; Brown 1987; Brown and Hartman in press; McMahon and Brown in preparation). Cold-branding was used to determine growth and movements of individual fish, to estimate population sizes in off-channel sites by mark-recapture, and to estimate contribution of specific sites to the total smolt output (Brown 1985; Brown 1987; Brown and Hartman in press; McMahon and Brown in preparation). Artificial stream channels were used to perform experiments on juvenile coho winter behaviour and habitat preferences under various types of cover and levels of flow (McMahon and Hartman in preparation).

WINTER HABITAT UTILIZATION

a) Fall Redistribution and Winter Movement

There was a marked climatic difference between the summer and winter period within a rain dominated west coast watershed such as Carnation Creek (Figure 1). The winter period extended from approximately October to April and was characterized

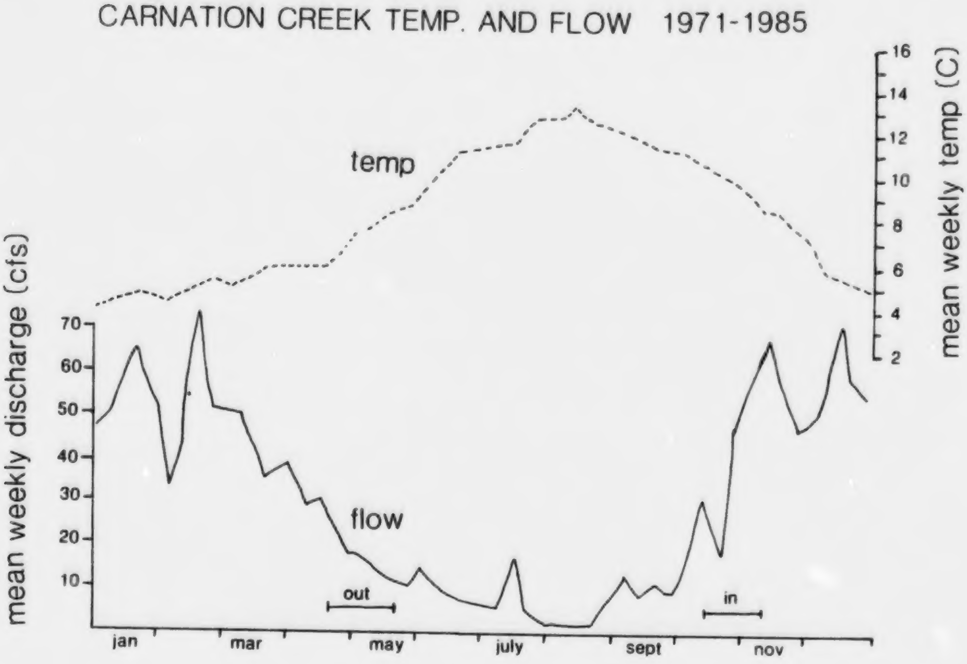

Figure 1. Mean weekly flow (ft^3/sec) and mean weekly water temperature (°C) as measured in Carnation Creek from 1971 to 1985. Juvenile coho movement out of off-channel sites in spring and movement into these off-channel sites in fall is indicated.

by low water temperatures (averaging 3-4° C) and frequent, severe freshets. During the summer, juvenile coho occupied pools and glides within the main-channel and the off-channel swamps and tributaries were dry.

In fall within the main-channel, juvenile coho moved from exposed pools to debris jams (Figure 2; McMahon and Brown in preparation). McMahon and Brown (in preparation) determined that the majority of coho moved to the nearest debris jam immediately downstream of their summer rearing location and remained within that debris jam for the entire winter period. Little upstream movement occurred and summer habitats were not re-invaded, even during periods of low flow.

In fall, juvenile coho also moved from the main-channel into flooded swamps and minor tributaries (Bustard and Narver 1975a; Tschaplinski and Hartman 1983; Brown 1985). Brown (1985) described this movement as either active (up through the swamp outlets) or passive (across the flood-plain). The magnitude of flow during the first fall storms established the degree of access and hence the number of coho which entered these sites (Brown and Hartman in press). Coho population size within off-channel sites peaked within two weeks of the first fall storms and declined gradually until out-migration the following spring (Figure 3; Brown 1985). Later storms, even though greater in magnitude than the initial fall freshets, elicited no further movement of coho into off-channel sites (Bustard and Narver 1975a; Tschaplinski and Hartman 1983: Brown 1985). Brown (1985) found that 67% of the juvenile coho that were uniquely marked in Oct-Nov were present in the same swamp the following March; 80% of these fish were recaptured within 10 m of the location they were originally marked in.

These observations demonstrate three important features of juvenile coho fall and winter movement. First, there is a distinct change in habitat type from exposed pools and glides in summer to more

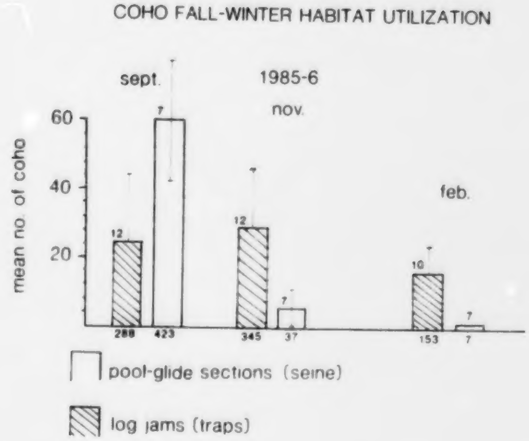

Figure 2. Mean number of coho utilizing two main-channel habitat types (pool-glides and log jams) during three periods: in fall before redistribution (Sept), in fall after redistribution (Nov), and late winter (Feb). Upper numbers refer to numbers and sites sampled, lower number indicates total catch; (adapted from McMahon and Brown in preparation).

protected (more cover and lower velocity water) debris jams and off-channel sites in winter. Second, the shift from summer rearing locations to winter habitats occurs at a specific time (first fall storms) and the increase in stream flow associated with these storms acts as a seasonal cue for coho to seek winter refuge. Third, the movement of juvenile coho in fall is a permanent shift rather than a temporary redistribution lasting only for a period of high streamflow.

b) Main-channel Winter Habitat

Two years after logging in Carnation Creek, Toews and Moore (1982) documented significant declines in the volume and stability of the large woody debris that Bustard and Narver (1975a) found to be the major component of juvenile coho, main-channel, winter habitat. This reduction in winter habitat occurred from main-channel debris being removed, fractured, and dislodged during logging operations and debris torrents (Hartman et al. 1987); without an adequate riparian leave-strip, this debris was not replaced. The intensive and careful treatment areas of Carnation Creek (1800m or 60% of the accessible length) were affected. The net result of these changes was that a structurally complex, debris rich section of stream became a channelized, debris impoverished stream reach.

Tschaplinski and Hartman (1983) compared the abundance of over-wintering coho in sections of the main-channel that were bordered by lands harvested with and without leave-strips. They found that the mean number of juvenile coho observed in clear-cut versus leave-strip sections showed a strong positive correlation with the total volume of debris (Figure 4). Based on their results, we calculated that unprotected sections averaged 93% less debris volume and 75% fewer over-wintering coho than leave-strip sections. Thus, the loss of large, stable debris in stream sections lacking a leave-strip greatly reduced the capacity of these areas to support over-wintering coho. The importance of large woody debris as winter habitat for coho and its reduction following streamside logging has also been noted in Alaska (Heifetz et al. 1986; Murphy et al. 1986), Oregon (House and Boehne 1986), and British Columbia (Tripp and Poulin 1986a, b).

In addition to size and stability, structural complexity of debris jams is also important in determining the suitability of main-channel winter habitat for coho. Underwater observations of numerous debris jams along the entire length of Carnation Creek, revealed that during winter coho are most abundant in debris jams composed of several large boles and a dense, intertwining root mass. In earlier winter habitat preference tests, Bustard and Narver (1975b) demonstrated that more coho remained in side pools having an overhanging bank and dense root mass, than in other less complex habitats (rubble, silted rubble, and barren).

To more clearly establish the features that constitute preferred winter habitat, McMahon and Hartman (in preparation) examined cover preferences of coho in stream channels having different types of cover and varying levels of flow. At low flows, few coho remained in channels lacking cover or with only a baffle to provide low velocity water (Figure 5). The number of coho remaining within the channels increased when a combination of overhead cover and a baffle were present. When complex cover in the form of a root mass was provided, 100% of the fish introduced into the channels remained. Under simulated freshet conditions, a cover combination of baffle, overhead shade, and root mass was the only cover type that permitted retention of the coho within the channels. Thus, to provide suitable winter cover, debris jams must provide a combination of features:

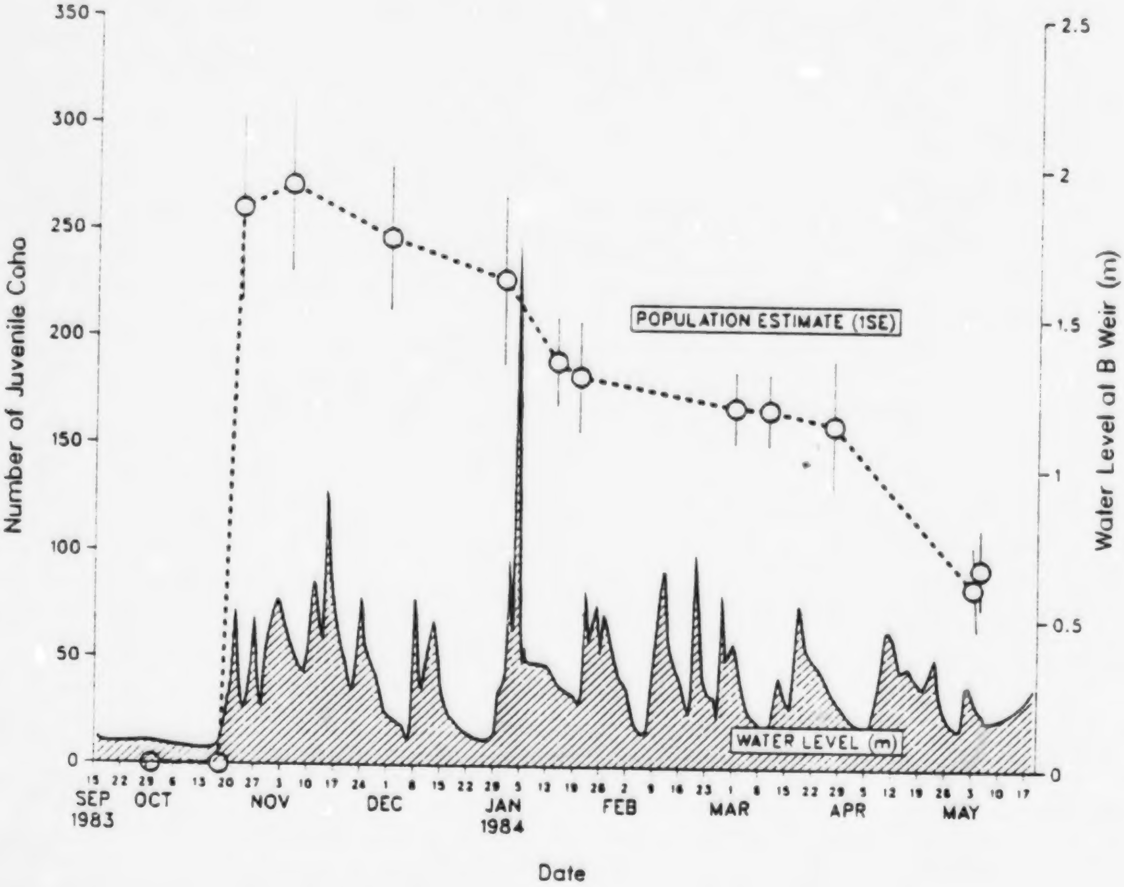

Figure 3. Change in juvenile coho population over a winter period within one ephemeral swamp (from Brown 1985).

low velocity water, shade, and a complex three-dimensional structure wherein fish can hide.

c) Off-channel Winter Habitat

Off-channel winter rearing sites are difficult to identify, especially in summer when they are dry. Brown (1985) and Brown (1987) indicated that these sites have many similar features such as:

1. dense emergent vegetation (ie. *Scirpus* sp.),
2. muck substrate (organic veneer or blanket),
3. high probability of flooding from main-stream, and
4. high summer water level (within 25 cm of surface).

The majority of the off-channel sites examined on the Carnation Creek flood-plain were located within isolated sections of old-channels that were formed when the main-channel altered its course. Most of these sites were associated with the valley walls and up-slope seepage maintained high water levels within these depressions during the winter.

Juvenile coho growth (Figure 6) was greater within these off-channel swamps than within the main-channel debris jams (Brown and McMahon in preparation). The reasons for this difference in winter growth were not clear, but appeared to be related to

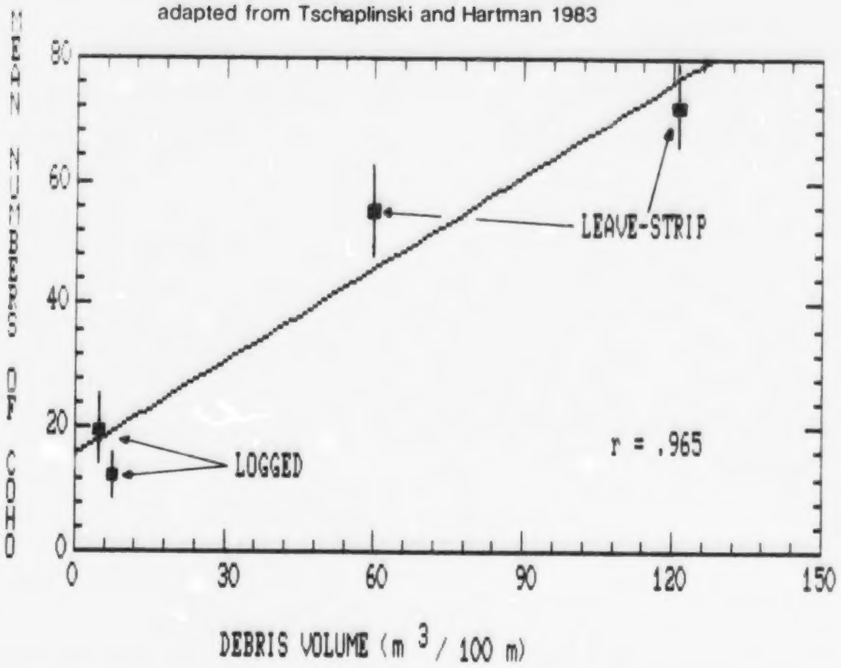

Figure 4. Relationship between debris volumes (m^3/100m of stream length) and mean numbers of coho over-wintering in four sections of Carnation Creek (adapted from Tschaplinski and Hartman 1983).

food availability, temperature and energy expenditure. The kinds of invertebrates observed in off-channel swamps were different from those found in the main-channel and these food organisms appeared to be more available off-channel. The off-channel sites were dominated by Chironomids, Tricoptera, Amphipods and specific Ephemeroptera such as *Amuletus* sp.; while main-channel benthic and drift samples were dominated by Ephemeroptera and Plecoptera. The winter temperatures were slightly warmer on average (approximately 0.5° C) within the off-channel sites and the range of temperatures available to rearing juvenile coho was greater. The off-channel sites were more protected from extremely high discharges and winter energy expenditure of off-channel rearing coho may have been less than that of main-channel rearing fish.

Juvenile coho winter survival has been reported to be higher off-channel than within the main-channel (Bustard and Narver 1975a; Tschaplinski and Hartman 1983). However, annual off-channel survival is highly variable and would depend upon annual climatic conditions such as, winter ice formation and desiccation in spring before out-migration can occur. Tschaplinski and Hartman (1983) did not detect a difference in off-channel use, before and after the watersheds of two small tributaries were logged.

d) Relative Smolt Contribution

The contribution of off-channel habitat to Carnation Creek's total smolt output was calculated for two winters (Figure 7). Although the size of the fall populations (8000 in 1982 and 10000 in 1983) and the total number of smolts produced in spring (3500 in 1982-83 and 3200 in 1983-84) was similar, the relative contribution of off-channel habitat to total smolt output differed (Brown and Hartman in press). The difference in spring (April-May) water levels appeared to govern the percentage contribution. Off-channel survival was lower during the warm dry spring of 1983 (Figure 7) and the stranding and death of juvenile coho observed within the off-channel sites at that time, further supports these results. Main-channel survival was reduced during winter 1983-84 possibly due to extremely high discharge producing storms. Thus, off-channel and main-channel survival is dependent upon different climatic factors.

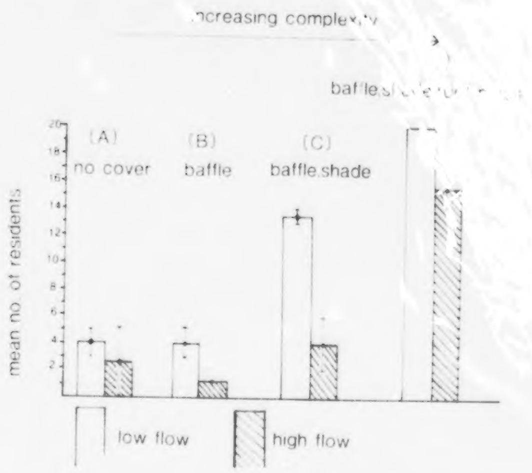

Figure 5. Mean numbers of juvenile coho remaining in artificial stream channels under flows representing a winter base flow (0.28 m^3/sec) and a small magnitude freshet (2.26 m^3/sec). Treatments include: (A) no cover — channel lacking any instream or overhead cover, (B) baffle — a plywood board attached at a 45° angle to simulate low velocity instream cover provided by a submerged log, (C) baffle/shade — a wood shade positioned behind the baffle to simulate an undercut bank providing both shade and low velocity cover, (D) baffle/shade/root mass — a root mass placed beneath the baffle and shade to simulate a debris jam providing shade, low velocity water and a complex of interstitial spaces, (from McMahon and Hartman in preparation).

MANAGEMENT OF WINTER HABITAT

a) Main-channel

Juvenile salmonids over-wintering within the main-channel of a west coast stream, require debris jams that are composed of a complex of large stable debris and are located downstream of summer rearing habitat. Tschaplinski and Hartman (1983), Murphy et al. (1986), and Martin et al. (1986) have demonstrated that piece size is the major component that determines the suitability of debris as winter habitat. Large woody debris such as root wads and full length tree stems are necessary to provide the stable base for debris jam formation. Large pieces are also necessary to capture and hold the smaller branches, stems and root masses that form much of the complexity of debris jams. Individual stems must be at least 3-4 m long, 25-35 cm in diameter, and 3 m^3 in volume to provide the stable, complex cover required by juvenile coho during the winter (Hartman and Holtby 1982; Hogan 1985; Martin et al. 1986; Tripp 1986).

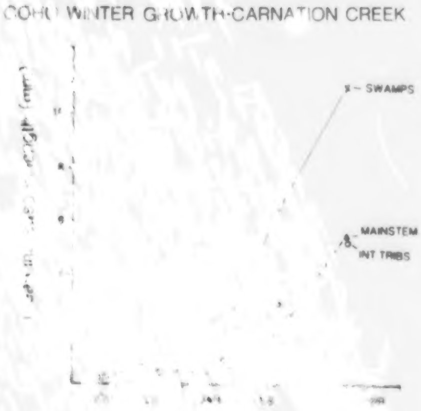

Figure 6. The mean [illegible] growth of individually marked juvenile coho from three habitat types: ephemeral swamps, intermittent tributaries, and main-channel locations (adapted from [illegible] and McMahon in preparation).

The more stable the large debris within the main-channel is, the more suitable it is as winter habitat. The stability of a debris jam can be reduced if the integrity of stream banks and channel is lost. A rapidly changing stream channel can isolate a stable jam, fill in pools created by debris jams or remove large debris from the channel. A stable channel structure is essential for maintaining stable debris jams.

The complexity of debris is another important consideration when evaluating its suitability as winter habitat. Experiments conducted by McMahon and Hartman (in preparation) showed that the best main-channel winter habitat was provided by debris which created both shade and numerous interstitial spaces within which the fish could find refuge from high water velocities. During freshets, large, structurally complex debris jams are essential to dissipate the energy of flowing water and create pockets of shelter. Single logs do not make good winter habitat

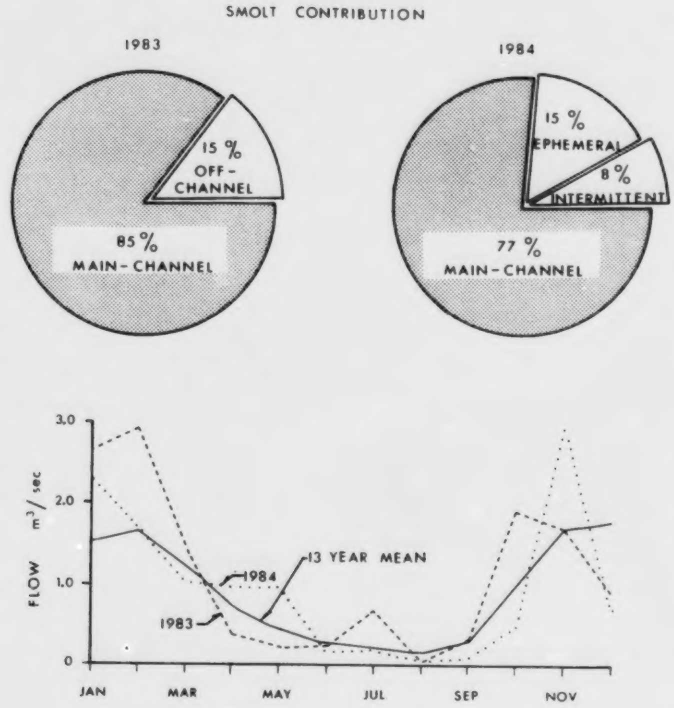

Figure 7. The percentage of smolts produced from off-channel and main-channel habitats and the average flow at B-weir during 1983 and 1984 in Carnation Creek.

(Tschaplinski and Hartman 1983; McMahon and Hartman in preparation). Siedelman (personal communication, cited in Sedell et al. 1984) reported that coho juveniles were 2-3 times more abundant in debris jams composed of two or more downed trees than in jams formed by a single log. Restoration projects on degraded streams have constructed gabions (e.g., House and Boehne 1985, 1986) or re-introduced large single trees (e.g., Tripp 1986) in streams to mimic the function of woody debris and thereby enhance fish habitat. Such improvements have increased spawning and summer habitat but their effectiveness in creating winter habitat is unknown. Results from the studies discussed above suggest these improvement structures may not have the complexity necessary to provide high quality over-wintering habitat. Ways to increase complexity of these structures are discussed by Hartman and Holtby (1982), Sedell et al. (1984), and Tripp (1986).

The distribution of winter habitat is another important factor to consider when restoration programs are initiated. Since coho move downstream to their over-wintering sites from their summer rearing sites (Cederholm and Scarlett 1982; Peterson 1980; Brown and McMahon in preparation), winter habitat should be spaced along the entire stream length and especially downstream from summer rearing areas to maximize its use. Hogan (1984, 1985), Tripp (1986), and Sedell et al. (1984) should be consulted for further guidelines on the optimal spacing of debris structures.

The maintenance of adequate old-growth riparian zones and the stream side management of second growth stands is a concern. One of the most important findings from Carnation Creek research has been that careful stream-side logging (instream debris was left in the channel and yarding was directed away from the streambank), a currently accepted practice for logging along streams in British Columbia (Brownlee and Morrison 1983) and Alaska (Murphy et al. 1986), was insufficient to maintain the integrity of main-channel debris jams. The integrity of debris jams and the complexity of the stream channel has been maintained only in the leave-strip sections.

The leave-strip has served to protect instream debris by reducing the amount of small debris entering the creek and by maintaining bank strength by keeping root networks alive (Hartman et al. 1986). However, the winter habitat for coho in this section is also at risk if accumulations of small and highly unstable debris located in upstream sections move downstream through this section during freshets. To maintain coho winter habitat in streams after logging, forest managers must therefore ensure that upstream as well as adjacent streamside logging activities protect debris in the main-channel.

Leave-strips are also essential to ensure continued recruitment of large woody debris into streams. Second growth forests will not produce the large stems necessary to form large, stable debris jams. It is also questionable wheather forest managers, after planting and maintaining stream side stands for 60 years or more, will permit a portion of them to fall into streams and rot. In a survey of second growth watersheds on the Olympic peninsula, Grette (1985) found that debris volume remains very low in logged streams for a least 40 years and does not begin to accumulate appreciably until more than 60 years after logging. Debris volumes do not return to pre-logging levels until 75 to 100 years (Martin et al. 1986).

b) Off-channel

The successful use of off-channel winter rearing sites by juvenile coho demands that a number of basic requirements be met (Brown 1985; Hartman and Brown in press). Access into off-channel sites in fall and from them in spring can be impaired if natural flooding patterns are altered, if entrances to minor drainages are blocked by debris, or if culverts and bridges are improperly installed. The swimming ability and habitat requirements of juvenile coho is not the same as for adults and should be considered during culvert installation.

Winter water levels must be maintained. Drainage of small swamps and the diversion of water away from off-channel sites during road building may eliminate winter habitat. Water water levels may rise slightly after harvest and this may improve winter habitat (Brown 1985).

Water quality must be sufficient to support fish. The muck substrate tends to be anerobic and if disturbed can generate lethal levels of H_2S. The small swamps and depressions located at the base of valley walls should not be thought of as catch basins that protect the main-channel from sediments produced from up-slope positions.

The physical nature of an off-channel site (substrate, emergent vegetation, and riparian vegetation) should not be disturbed. The muck substrate is sensitive to mechanical disturbance and is held in place by emergent vegetation. Juvenile coho grow within the off-channel sites during the winter (Brown and McMahon in preparation), thus both aquatic and riparian vegetation may be important elements in the trophic pathways. The elimination of vegetation by either mechanical or chemical means could reduce smolt production from these sites.

SUMMARY

Winter habitat such as small ephemeral swamps are hard to identify, especially during the summer when they are dry. Only through difficult winter surveys can this habitat be identified. Once identified, however, it is difficult to evaluate the benefits of protection or enhancement practices due to the high annual variation in use and survival within these sites. Resource managers must recognize that each habitat type has unique values that are influenced differently by environmental factors and forestry practices. Thus, positive influences which enhance one habitat type may off-set negative influences which damage another.

Once identified and evaluated, it may still be difficult to justify protection or enhancement of small muck bottomed swamps and debris jams. Human bias as to what "looks like good winter habitat" has to be replaced by a firm knowledge of what is the most valuable coho winter habitat and why it is of value. The short-term monetary benefits of streamside timber removal must be weighted against the long-term costs of habitat loss which are more difficult to quantify.

The protection of juvenile coho winter habitat through maintenance of old-growth riparian zones and through future harvesting guidelines for second growth timber is a concern. Current protection guidelines may be inadequate to protect and maintain coho main-channel winter habitat over the next forest rotation. It must also be recognized that present day cutting patterns will establish the cutting patterns during the next forest harvest. Habitat managers must not be constrained by current short-term policies, but must be committed to long-term research and planning.

In this paper we have only dealt with one: species (coho), life stage (juvenile), season (winter) and stream system (Carnation Creek). Other species and life stage have different requirements. Coho juveniles over-wintering in snow dominated interior watersheds will encounter different problems. The findings from our studies can only be applied to juvenile coho over-wintering in rain-dominated coastal streams and extreme caution in extrapolation to other species or watersheds is stressed.

ACKNOWLEDGMENTS

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LITERATURE CITED

Brown, T.G. 1985. The role of abandoned stream channels as over-wintering habitat for juvenile salmonids. M.Sc. thesis, University of British Columbia, Dept. of Forestry, Vancouver, B.C. 134p.

Brown, T.G. 1987. Characterization of salmonid over-wintering habitat within seasonally flooded land on the Carnation creek flood-plain. B.C. Min. For., Land Manage. Rep. No. 44. 17p.

Brown, T.G. and G.F. Hartman. In press. The contribution of seasonally flooded lands and minor tributaries to the production of coho salmon in Carnation Creek, British Columbia. Trans. Amer. Fish Soc.

Brown, T.G. and T.E. McMahon. in preparation. Winter growth of juvenile coho in Carnation creek.

Brownlee, M.J. and D.C. Morrison. 1983. A preliminary fisheries examination of the content, application, and administration of the stream protection clauses ("P" clauses) on Vancouver Island, p. 31-73, In: Fish habitat protection and planning for forest harvesting in coastal streams of British Columbia: some research and management implications. Can. Ind. Rept. Fish. Aq. Sci., No. 143. 73p.

Bustard, D.R. and D.W. Narver. 1975a. Aspects of the winter ecology of juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). J. Fish. Res. Board Can. 32:667-680.

Bustard, D.R. and D.W. Narver. 1975b. Preferences of juvenile coho salmon (*Oncorhynchus kisutch*) and cutthroat trout (*Salmo clarki*) relative to simulated alteration of winter habitat. J. Fish. Res. Board Can. 32:681-687.

Cederholm, C.J. and W.J. Scarlett. 1982. Seasonal immigrations of juvenile salmonids into four small tributaries of the Clearwater River, Washington, 1977-1981, p. 98-110, In: E.L. Brannon and E.O. Salo [Eds.]. Salmon and trout migratory behavior symposium. College of Fisheries, University of Washington Press, Seattle, WA.

Grette, G.B. 1985. The role of large organic debris in juvenile salmonid rearing habitat in small streams. M.S. thesis, Univ. Washington, Seattle. 105p.

Hartman, G.F. and T.G. Brown. 1988. Forestry-fisheries planning considerations on coastal floodplains. The Forest Chronicle 64:47-51.

Hartman, G.F. and L.B. Holtby. 1982. An overview of some biophysical determinants of fish production and fish population responses to logging in Carnation Creek, British Columbia, p 348-374. In: G.F. Hartman [Ed.]. Proceedings of the Carnation Creek Workshop, a 10-year review. Pacific Biological Station, Nanaimo, British Columbia. 404 p.

Hartman, G.F., J.C. Scrivener, L.B. Holtby, and L. Powell. 1987. Some effects of different streamside treatments on physical conditions and fish population processes in Carnation Creek, a coastal rain-forest stream in British Columbia, p. 330-372 In: E.O. Salo and T.W. Cundy [Eds.]. Streamside management: forestry and fishery interactions, College of Forest Resources, University of Washington, Seattle, WA.

Heifetz, J., M.L. Murphy, and K V. Koski. 1986. Effects of logging on winter habitat of juvenile salmonids in Alaskan streams. No. Amer. J. Fish. Manage. 6:52-58.

Hogan, D. 1984. The influence of large organic debris on channel morphology in Queen Charlotte Island streams. Proc. West. Assoc. Fish Wildl. Agencies 1984:263-273.

Hogan, D. 1985. Stream channel morphology: Comparison of logged and unlogged watersheds in the Queen Charlotte Islands. M.Sc. thesis, Dept. of Geography, University of British Columbia, Vancouver. 206p.

House, R.A. and P.L. Boehne. 1985. Evaluation of instream enhancement structures for salmonid spawning and rearing in a coastal Oregon stream. Nor. Amer. J. Fish. Manage. 5:283-295.

House, R.A. and P.L. Boehne. 1986. The effect of instream structures on salmonid habitat and populations in Tobe Creek, Oregon. North Am. J. Fish. Manage. 6:38-46.

McMahon, T.E. and T.G. Brown. In preparation. Winter movement of juvenile coho in Carnation Creek.

McMahon, T.E. and G.F. Hartman. in preparation. Winter cover requirements of juvenile coho salmon (*Oncorhynchus kisutch*).

Martin, D.J., L.J. Wasserman, and V.H. Dale. 1986. Influence of riparian vegetation on posteruption survival of coho salmon fingerlings on the west-side streams of Mount St. Helens, Washington. No. Amer. J. Fish. Manage. 6:1-8.

Murphy, M.L., J. Heifetz, S.W. Johnson, K V. Koski, and J.F. Thedinga. 1986. Effects of clear-cut logging with and without buffer strips on juvenile salmonids in Alaskan streams. Can. J. Fish. Aq. Sci. 43:1521-1533.

Peterson, N.P. 1980. The role of spring ponds in the winter ecology and natural production of coho salmon (*Oncorhynchus kisutch*) on the Olympic Peninsula, Washington. M.Sc. thesis, University of Washington, Seattle. 96p.

Sedell, J.R., F.J. Swanson, and S.V. Gregory. 1984. Evaluating fish response to woody debris, p. 222-245. In: Proc. Pacific Northwest Stream Habitat Management Workshop, Humboldt St. Univ.

Tripp, D.B. 1986. Using large organic debris to restore fish habitat in debris-torrented streams. B.C. Min. For., Land Manage. Rep. No. 47.

Tripp, D.B. and V.A. Poulin. 1986a. The effects of mass wasting on juvenile fish habitats in Queen Charlotte Island streams. B.C. Min. For., Land Manage. Rep. No. 45.

Tripp, D.B. and V.A. Poulin. 1986b. The effects of logging and mass wasting on salmonid juveniles in Queen Charlotte Islands streams. B.C. Min. For., Land Manage. Rep. No. 46

Toews, D.A.A. and M.K. Moore. 1982. The effects of streamside logging on large organic debris in Carnation Creek. B.C. Min. For., Land Manage. Rep. No. 11. 29p.

Tschaplinski, P.J. and G.F. Hartman. 1983. Winter distribution of juvenile coho salmon (*Oncorhynchus kisutch*) before and after logging in Carnation Creek, British Columbia, and some implications for overwinter survival. Can. J. Fish. Aquat. Sci. 40:452-461.

THE EFFECTS OF LOGGING ON STREAM TEMPERATURES AT CARNATION CREEK

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The measurement and modeling of stream temperatures were important parts of the Carnation Creek study for two reasons. First, stream temperature is a fundamental component of the habitat of poikilothermic ("cold-blooded") animals such as fish. Changes in stream temperatures can cause changes in the metabolic rates of fish which can lead to changes in such things as egg development times, maturation rates and activity levels. Second, changes in stream temperatures were expected immediately after logging and were expected to persist until the canopy closed over the stream again, some 15-30 years after logging. Consequently, some of the first responses of the stream biota to logging perturbations were expected to be caused by changes in stream temperatures and those effects were expected to persist for the duration of the study.

The objective of this paper is to briefly document the effects of logging on stream temperatures at the main hydrological weir. I will describe a correlative model that was used to predict stream temperatures and to quantify the effects of logging.

METHODS

Continuous records of air temperature and incident solar radiation were collected from a cleared hilltop near the mouth of the stream. Continuous rainfall records were collected nearby at the main camp and continuous water temperature and discharge records were collected at the main hydrological weir (B-weir). There is now a continuous record of weather conditions, stream temperatures, and stream discharge extending for over 15 years.

The determining factor that governs stream temperatures is the amount of incoming solar radiation (Brown 1969). Logging near a stream removes the forest canopy and increases the amount of sunlight which reaches the stream surface. Most of the radiant energy reaching the surface of the stream is stored in the stream water. Losses through re-radiation of long-wave energy, such as those that occur at night, are small compared to the short-wave energy inputs from sunlight. For stream reaches that are less than 1 km in length, other modes of heat exchange, (convection, conduction and evaporation), are insignificant compared to the two forms of radiation (Beschta et al. 1987).

Causal models that predict stream temperatures are based on energy balance equations (Brown 1969). Although such models can redict stream temperatures in short stream reaches very accurately, extensive data collected at very short time intervals is required. The use of causal models to predict the temperatures of small streams, even those as small as Carnation Creek, is a complex task (Beschta et al. 1987) and is probably not practical. Certainly, the types of data collected at Carnation Creek were never intended to provide the information necessary to develop such a causal model of stream temperatures. Instead, the data were intended to document temperature responses to logging. However, in order to quantify the effects that logging had on stream temperatures it was necessary to develop a model that would predict stream temperatures had logging not occurred. The model that was developed exploits a correlative relationship between air and water temperatures. The use of air temperature to predict water temperature does not imply that convective transfers of heat between the air and the stream are important components in the heat budget of the stream. Instead, the term indicates that there is a statistical relationship between the two temperatures.

The model is a multiple linear regression with three groups of independent variables (Table 1). The air temperature term summarizes most of the seasonal variation in stream temperatures and estimates the effects of coarse climatic variability. The terms for the months estimate month to month variations in the correlative relationship between air and stream temperatures. The month X logging terms estimate by month, the effects of logging on stream temperatures. The extent of logging was quantified as the proportion of the stream bank along the main-stem and major tributaries that had been logged, weighted by the aspect (north, south etc.), and the distance of the center of the logged reach from the hydrological weir.

Mean weekly water temperatures at the main hydrological weir are predicted. Temperature changes at this site were the summed response of the stream to about 95% of the logging within the watershed. The weekly period (as opposed to daily or monthly eriods) was chosen primarily because it was the shortest period that was not overly affected by the vagaries of the weather but also for the technical reason that it was the shortest period that did not produce problems with the auto-correlation of residuals.

The model allows the prediction of stream temperatures in the absence of logging. This is accomplished by setting all of the "logging X month" terms to zero while using observed time series of air temperatures. This calculation assumes that the strong correlation between stream and air temperatures that was observed before logging was not a spurious one and that the relationship would have remained unchanged had logging not occurred. The basis of the correlation between air and stream temperatures does not need to be known.

RESULTS AND DISCUSSION

Average stream temperatures during the summers before logging were several degrees cooler than might be expected based on latitude (Fig. 1). In other areas of the Pacific northwest summer stream temperatures in pristine forests are often as warm or warmer than those observed at Carnation Creek after it was logged (Beschta et al. 1987). In such streams, the responses of the stream biota to any increases in stream temperatures that might occur after logging could be very different from those observed in Carnation Creek.

There is no doubt that logging resulted in increased stream temperatures. The increases were seen after the first major clear-cut in the winter of 1976/77 (Fig. 2B). Note that there were no corresponding changes in monthly air temperatures during the period of logging (Fig. 2A). The parameter estimates of the "month X logging" terms of the temperature model estimate the effects of logging on stream temperatures (Table 1). Logging resulted in significantly higher stream temperatures in all months of the year. The increases ranged from 0.7°C in December to 3.2°C in August. The largest increases were observed during the summer months when energy inputs to the stream from solar radiation were greatest.

The effects of logging on stream temperatures were summarized by calculating thermal summations over three biologically interesting periods (Fig. 3). The observed thermal summations are compared to estimates generated by the model with all of the "logging X month" terms set to zero, i.e. it was assumed that logging had not occurred. The greatest effects of logging were seen in the summer when thermal summations increased by 37% after logging (Fig. 3C). Thermal summations increased approximately 15% during the winter (Fig. 3A) and by 27% during the spring (Fig. 3B).

The effects of logging on stream temperatures can be further examined by comparing the stream temperatures observed after logging with temperatures in a pristine stream summarized for many decades. Doing so allows the effects of logging to be examined in the context of long-term variation in the regional climate. Although stream conditions have been monitored at Carnation Creek for 15 years this period of time is not adequate to establish what natural variability in the pristine state would have been. However, the stream temperatures observed before logging are strongly correlated with the average air temperatures reported at several coastal sites on the west coast of Vancouver Island for which long historical records exist. Using the air temperature records from one of these sites (Estevan Point) I calculated a simple linear regression predicting monthly mean water temperatures at Carnation Creek before logging. Using this

Table 1. Multiple regression model for stream temperature at the main hydrological weir. Air temperatures were measured at the main weather station (A). Stream and air temperatures are weekly means. The monthly terms have the value of 1 during the referenced month and zero during all other months. The "month X logging" terms have the value of weighted proportion of the streambank logged during the referenced month and zero during all other months. The weighting scheme is detailed in the text. The coefficient of determination (R^2) with n=694 and 669 degrees of freedom is 0.954.

variable	parameter estimate	p(2 tail)
constant	3.482	<0.001
air temperature	0.379	<0.001
monthly terms		
January	-0.847	<0.001
February	-1.249	<0.001
March	-1.294	<0.001
April	-1.051	<0.001
May	-0.287	0.189
June	1.088	<0.001
July	1.752	<0.001
August	2.149	<0.001
September	1.519	<0.001
October	1.435	<0.001
November	0.743	<0.001
monthly logging effects		
January	0.937	<0.001
February	1.405	<0.001
March	2.020	0.002
April	2.235	<0.001
May	2.935	<0.001
June	2.949	<0.001
July	2.976	<0.001
August	3.247	<0.001
September	2.903	<0.001
October	1.643	<0.001
Novermber	1.364	<0.001
December	0.711	0.001

relationship I then calculated the monthly mean water temperatures at Carnation Creek for the period 1923-1975 (Fig. 4). The response of stream temperatures to logging can be viewed against this summation of probable historical variability (Fig. 4). From June through October the stream temperatures observed after logging exceeded the probable historical bounds. In the remaining months, stream temperatures were unusually warm during most of the post-logging years.

SUMMARY

Stream temperatures in Carnation Creek rose after logging. Increased stream temperatures were observed in all months of the year, with the largest increases observed during the summer. The increases were roughly proportional to the length of the streambank logged. Although it is probable that stream temperatures rose after logging because of the increased enetration of sunlight to the stream,

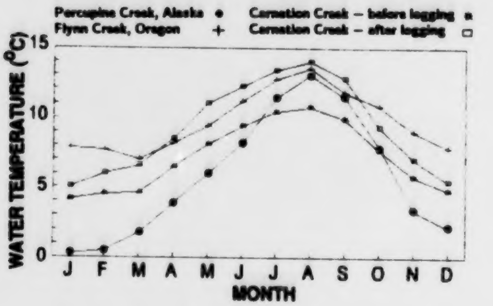

Figure1. Mean monthly stream temperatures in three forested streams in the Pacific northwest: Flynn Creek in Oregon, Carnation Creek and Porcupine Creek in Alaska. Stream temperatures in Carnation Creek after logging are also shown. Note that before logging summer temperatures in Carnation Creek were considerably lower than those in the other two streams, but that winter temperatures were indicative of stream latitude.

this hypothesis cannot be tested with the data collected.

LITERATURE CITED

Beschta, R.L., R.E. Bilby, G.W. Brown, L.B. Holtby, and T.D. Hofstra. 1987. Stream temperature and aquatic habitat: fisheries and forestry interactions, p. 191-232. In: E.O. Salo and T.W. Cundy [Eds.].Streamside management: forestry and fishery interactions, College of Forest Resources, University of Washington, Seattle, WA.

Brown, G.W. 1969. Predicting temperatures of small streams. Water Resour. Res. 5:68-75.

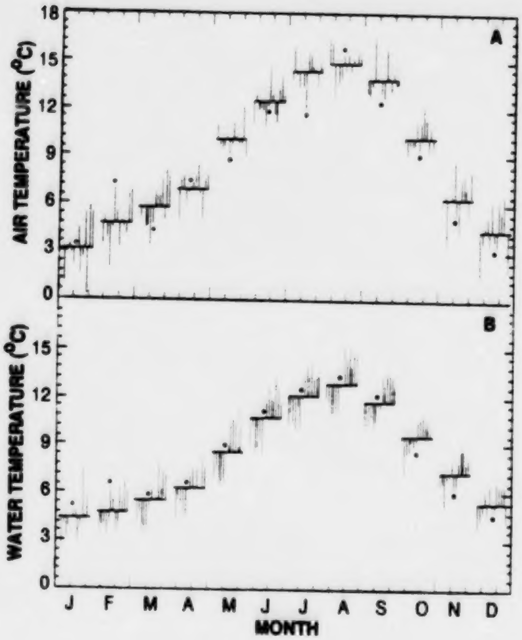

Figure 2. Seasonal sub-series plots of (A) air and (B) water temperatures in Carnation Creek. For each month the average temperature is shown as a horizontal line. The observed temperatures from April 1971 through September 1984 are shown as deviations from the monthly mean by a vertical line. The earliest year is on the left. The bar for 1977, the year following the first extensive logging during the winter of 1976/77 is indicated by a small dot. Comparison of the air and water temperature times series clearly shows that water temperatures were elevated by logging in all months from March through October.

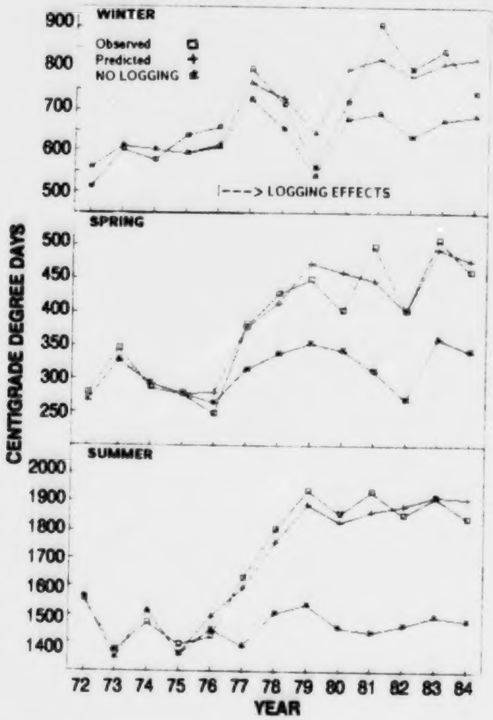

Figure 3. Thermal summations for the periods: (A) winter (Oct.-Feb.); (B) spring (Mar. & Apr.); (C) summer (May-Sept.). The estimated values were calculated using the model of Table 1. The "NO LOGGING" estimates were calculated by setting all of the "month X logging" terms to zero.

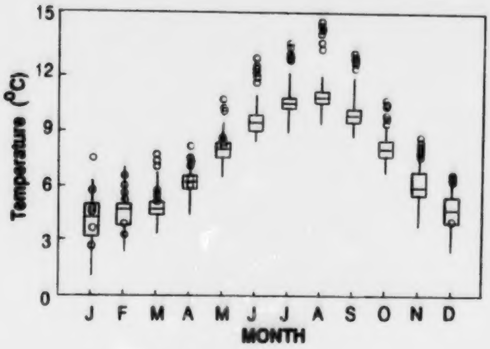

Figure 4. Box and whisker plots of mean monthly stream temperatures in Carnation Creek from 1923-1975. The stream temperatures were predicted from air temperatures at Estevan Point, B.C. using a linear regression calculated over the period 1971-1975. For each month the lower and upper limits of the box are the 25% and 75% percentiles respectively. The horizontal line bisecting each box is the median temperature for that month. The whiskers or solid vertical lines extending above and below the boxes show the range of values. The mean temperatures observed after most logging had been completed, 1979-1984, are shown as open circles.

THE USE OF ESTUARIES AS REARING HABITATS BY JUVENILE COHO SALMON

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INTRODUCTION

The use of the Carnation Creek watershed by juvenile coho salmon (*Oncorhynchus kisutch*) is not limited to fresh water. The upper intertidal zone of the stream is also inhabited by coho fry and smolts. Fry rear in the estuary generally between April and October. Yearlings co-occur with these fry for variable periods of time in spring and early summer before the processes involved with the smolt transformation are completed and new smolts subsequently emigrate to marine habitats.

Comprehensive research on the ecology of estuary coho was undertaken to describe for the first time

(1) their population dynamics and life histories;

(2) the physiological adaptation of coho fry to the brackish estuarine environment; and,

(3) their food resources and feeding behavior. Comparative stuides on populations of juvenile coho salmon inhabiting the stream and estuary at Carnation Creek were conducted in the field between1979-1981 and in the laboratory between 1981-1984. The population dynamics of stream and estuary coho were compared for 1979-1980. Seasonal numbers, habitat preferences, distribution, survival, and growth rates of both stream and estuary fish were determined in detail and summarized elsewhere (Tschaplinski, 1982, 1987). Investigations on comparative physiology and on the physiological adaptation of coho fry to the estuarine environment were undertaken in 1981-1982 and also detailed previously (Tschaplinski, 1982,1987). The salient points of these analyses will be reviewed presently together with a synthesis of some of the research conducted on the food resources and feeding ecology of stream and estuary coho.

Specifically, studies of estuary-dwelling coho were undertaken to determine whether (a) estuaries are able to support significant numbers of coho salmon fry; (b) coho fry displaced seaward could adapt physiologically and behaviourally to estuarine conditions and consequently take advantage of high environmental productivity and grow rapidly; and, (c) rapidly growing, estuary-reared fry could contribute important numbers of recruits to adult populations and the coho fishery.

In turn, the objectives of studies on the food resources and feeding relationships of stream-dwelling and estuarine coho were to first identify and quantify potential sources of coho food, namely aquatic drift, benthic macroinvertebrates, and terrestrial prey. Second, analyses were performed to determine which of these food resources were the most important to young coho both temporally and between environments. Ultimately, these studies revealed whether the secondary production assumed available to coho was estimated accurately from drift, terrestrial, and benthos samples, and whether environmental differences in food abundance and availability could account for differences in growth rates and production observed between stream and estuary fry.

The objectives of the trophic analyses were met through procedures in which (a) the numbers and distribution of potential prey species in Carnation Creek and its estuary were quantified and compared from spring to late summer; (b) the species and quantities of prey actually consumed by stream and estuary coho were assessed on both diel and seasonal bases; and, (c) the stomach contents of coho predators were correlated statistically with the species and quantities of invertebrate prey found in drift, terrestrial, and benthos samples.

Revealing how the prey preferences and feeding behavior of young coho vary in response to changes in prey availability in different environments under different conditions of stream dishcarge (e.g., freshets), tidal cycling (estuaries), terrestrial vegetation, season, and time of day is important not only to elucidate the trophic ecology of this species, but also for resource managers and fish culturists concerned with maintaining optimum conditions for coho growth in both natural habitats and artificial rearing structures such as estuarine pens (Heard and Crone,1976) or streamside channels (Mundie, 1974). The present investigation on coho juveniles inhabiting two environments differing widely in physical and chemical conditions, as well as biological productivity, has contributed information interrelating the processes which determine their numbers, distribution, growth, and production in natural populations. The understanding of these interrelationships supports the general objectives of research at Carnation Creek which are to (a) identify and comprehend the biological and physical processes operating within a coastal watershed system; (b) reveal ways in which forest removal changes these processes; (c) allow managers to make reasonable and useful decisions about land use and fish populations; and, (d) employ these results in evaluating logging regulations applied in the past.

METHODS

Procedures and materials employed in studies of seasonal population numbers, distribution, survival, growth rates, and adaptive physiology are detailed elsewhere (Tschaplinski, 1982, 1987). However, a brief summary of methods employed to determine the seasonal food resources and feeding habits of stream and estuary coho is included presently (see Tshaplinski, 1987, for detailed descriptions).

Frequent and "simultaneous" sampling of both juvenile coho and their prey was undertaken between 1979-1981 to determine the trophic dynamics of stream and estuary populations. Three sources of prey were identified in both the stream and estuary: (1) populations of benthic macroinvertebrates; (2) drifting invertebrates ("drift") consisting mainly of benthic, aquatic invertebrates and terrestrial insects carried downstream by the current; and, (3) terrestrial invertebrates, mainly aerial insects, associated with the air-water interface.

Benthic populations were compared approximately monthly by taking five to eight bottom samples in each environment using a ~0.3m^2 modified, Hess sampler. Coho fry and yearlings were collected for stomach-content analyses also at near-monthly intervals from late June to early October, 1979, late May to early October in 1980, and on 1-2 May 1981. At the "same time" that fish were seined, drift samples were collected at each study site using four drift nets of 250μm mesh and and 15cm X 15cm aperture. Additionally, terrestiral invertebrates active at the water surface were sampled at each site using six 0.5m X 0.5m sticky traps constructed from transparent polyvinyl sheets which were oriented at the air-water interface and anchored to the channel bottom using four iron rods.

In each monthly study, coho and their potential prey were sampled "simultaneously" over 24-hour (diel) periods at 4-hour intervals in 1979 and at 3-hour intervals in 1980 and 1981. Each sample, of coho included 8-12 individuals of sizes representing those present in each population. High tides interrupted continuous sampling in most estuary studies; otherwise, investigations on coho diet were designed such that predators and potential prey were sampled continuously.

To assess the potential food resources in both the stream and estuary, (1) benthic populations were quantified in terms of no./m^2 and compared parametrically between environments using $\log_{10}(x+1)$ transformations (Student's t, two-sample analysis of variance; $p \leq 0.05$); while (2) drift was quantified in terms of no./m^3•h; and, (3) surface-trapped, terrestrial prey were expressed in terms of of no./m^2•h. Both drift and surface-trapped invertebrates were compared nonparametrically between environments (Mann-Whitney, two-sample tests; $p \leq 0.05$).

To quantify the food organisms actually consumed by stream and estuary fry and yearlings, each prey item contained within the foregut (cardiac region of the stomach) was enumerated, classified to the lowest possible taxon, and identified as either aquatic, "estuarine-aquatic" (unique to estuarine or marine habitats), or terrestrial in origin. Diel or duirnal feeding frequencies were determined as no. of prey/fish·3 h sampling interval and estimated directly from the numbers of loosely-compacted (undigested), recently-consumed prey items in the foreguts of sampled fish. Feeding rates were then compared parametrically between stream and estuary coho (two-sample analysis of variance; $p \leq 0.05$).

Ranking prey by percent numerical abundance (% N) usually provided the most accurate representation of the relative importance of different food organisms in the diets of stream and estuary coho. Other indices such as percent frequency of occurrence (% F), volume (% V), or IRI (Index of Relative Importance = % F(% N + % V); Pinkas et al. 1971) added information largely redundant to that already provided by numbers because (a) numerically important prey also displayed high frequency of occurrence percentages (i.e., were consumed by most individuals); and, (b) most prey fell within a narrow range of sizes. Over 95% of all prey eaten by estuary coho were between 0.250-8.157 mm long X 0.150-1.270 mm wide. Correspondingly, >95% of the prey of stream coho were between 0.250-6.831 mm long X 0.150-1.575 mm wide.

The taxonomic composition of the coho diet was thus quantified numerically and compared with the numerical proportions of species occurring in samples of drifting, benthic, and terrestrial invertebrates. Comparisons were made using the index of Moriseta (1959) modified by Horn (1966) to determine the overlap between diet and potential food resources. This index sums all "potential" and "actual" prey species within the same habitat and is given as S where "S" is the total number of food

$$C_\lambda = \frac{2\sum_{i=1}^{S} x_i y_i}{\sum_{i=1}^{S} x_i^2 + \sum_{i=1}^{S} y_i^2}$$

categories (taxa), "x_i" is the proportion (numerical %) of the total diet of predator species "x" taken from food category "i", and "y_i" is the numerical proportion of the total drift (benthos, or terrestrial prey) also composed of category "i". The amount of overlap (C_λ) varies from an upper limit of 1 when the species proportions of the diet are the same as those of an environmental sample, to 0 when the respective populations have no species in common. The overlap values are the same as the average of the alpha (α) competition values used by MacArthur and Levins (1967); accordingly, it has generally been accepted that any value of $C_\lambda \geq 0.60$ demonstrates "significant" overlap although the index is descriptive.

After the overlap values between diet and benthic, drifting, and terrestrial prey sources were determined, the source showing the highest significant C_λ value was selected for statistical analyses of prey "preference". The "Linear Index of Food Selection" (Strauss, 1979, 1982) was used to determine whether stream or estuary coho were feeding upon individual prey species in proportion to the numerical abundance of each prey type in the environment or whether some prey items were being taken preferentially over others. The index compares linearly and statistically, the proportion of each individual prey type occurring in the diet with the proportion occurring in a prey "community", and is given as: $L = r_i - p_i$, where "r_i" is the numerical proportion (percent) of prey species "i" in the diet and "p_i" is the corresponding proportion sampled from the prey community. "Selection" values range from -1 when prey species are avoided or are temporally or spatially unavailable to +1 when prey are "preferred" or are more readily available than others. Values near 0 indicate that predators are consuming prey in proportions the same as those occurring in the environment; that is, no prey selection is occurring.

The Linear Index has been used frequently because "L_i" has the advantage of being normally distributed (Strauss, 1979, 1982; Ready, et al. 1985) thus allowing statistical comparisons (Student's t-tests) to be made between values. Because "L_i" is a linear combination of "r_i" and "p_i", it has a variance equal to the sum of the variances of "r_i" and "p_i": $S^2(L_i) = S^2(r_i) + S^2(p_i)$. Because multiple samples were used to estimated "r_i" and "p_i", the prey proportions used to calculate these values are the mean "r_i" and "p_i" weighted by the total number of prey in each sample (see Ready et al. 1985, Tschaplinski, 1987).

These analyses combined illustrated which source of invertebrate prey was the most important for stream and estuary fry, whether some prey were sought preferentially over others, and therefore, whether coho were able to use different prey sources and species efficiently in either environment.

RESULTS AND DISCUSSION

Life History, Habitat Preferences and Population Ecology

Estuary-dwelling coho salmon consist mainly of fry which emerge annually in large numbers from coastal streams between early spring and midsummer. Fry first emigrated downstream and inhabited the estuary within one week after they were first observed to emerge from the stream gravels. Observations of fry numbers, distribution and behavior from late February to mid-March (1981) provided no evidence of density-dependent causes for this early emigration. Numbers of stream fry were low in early spring. Many pools and other low-velocity sites, which are prime habitats for coho fry, contained few or no individuals. The overall density of fry during the first week of emergence was > 16-times lower than the 11-yr average recorded for late-summer populations in Carnation Creek. By 30 April (1981) > 9 000 fry emigrated from the stream although numbers were low and no aggressive interactions were observed among them even after populations had increased to 0.71 fry/m^2 in one study section.

The seasonal peak of fry emigration coincided with (1) the emergence of large numbers of coho into high-velocity riffles and runs; and, (2) the onset of seasonally high discharge volumes including freshets of 3 m^3/s between March and early April. Over 90% of all emigration in 1981 occurred during that period. The co-occurrence of these events infers that fry were physically displaced downstream by the actions of rapid currents. These conclusions are corroborated by the results of other investigations in Carnation Creek (Holtby and Hartman, 1982) and elsewhere (Au, 1972).

Observations made from 1979-1981 revealed that the numbers and distribution of coho fry were stongly space-limited. The total length of the estuary was 490 m when the lengths of the main channel and all side channels were summed. However, only the uppermost 250 m contained habitats suitable for juvenile coho. From May to late September/early October, fry inhabited all low-velocity sites of this upper zone which consisted of an alternating sequence of riffles and pools at low tide. The upper estuary is sheltered from the open waters of Barkley Sound by high, vegetated banks, and contains complex salinity and temperature gradients both horizontally and vertically in the water column. Measurements made at both low and high tides revealed that salinities ranged from 0-21‰, and temperatures varied from 8.9-19.0°C from June to late September.

These salinities and temperatures neither limited nor determined coho distrubution: based upon pool area at low tide, overall densities of fry in the estuary in 1980 were found to approximate those occurring upstream in fresh water. Late-summer densities varied from 1.06-1.53 fry/m^2 and were statistically equal to the 11-year mean. However, the distribution of estuarine coho was very irregular and depended upon habitat structure. Habitat space was the prime factor determing the numbers and distrubution of both fry and yearlings.

Preferred habitats of estuary coho were defined by water depths, current velocities, and overhead cover, and were the same as those of their stream-dwelling counterparts. The largest numbers of fry were always found in sites containing at low tide (1) low-velocity water averaging 8.7 cm/s and ranging between 0-32 cm/s; (2) pools usually 45-225 cm deep; and, (3) cover in the form of (a) undercut banks, often with vegetation overhanging the channel, and (b) masses of large debris (partially-submerged tree roots, logs, and fallen trees). Large, woody debris provides important structural habitat for coho fry occurring in estuaries by creating pools, furnishing shelter, and reducing water velocities and substrate movements. Estuary sections containing these features supported fry at densities varying up to 5 fry/m^2 during summer. Based on pool area, these sections held up to 17-times more fry than did broad, shallow reaches devoid of cover. Clearly, coho fry do not change their habitat preferences after they emigrate from streams to estuaries.

In 1979-1980, 1,205 and 2,453 fry remained in the estuary by late summer, amounting respectively to ~9-12% of the total numbers inhabiting the stream. Estuaries can thus provide additional habitats for coho fry, thereby retaining seaward-displaced fish that appear otherwise to be lost to the populations rearing in coastal watersheds. After emigrating to the estuary, coho fry rapidly outgrew their stream-resident counterparts by 1.8-2.3 fold during their first summer and were 16-18 mm longer on average by late September 1979-1980. As a consequence of accelerated growth, estuary fry comprised a greater proportion of the total population rearing in the watershed in terms of biomass than they did numerically. Between ~20-24% of the total-stream biomass was accounted for by fry rearing intertidally over the same two years.

The estuary population demonstrated its greatest importance trophically in terms of net production which summed to 6.92 kg during May-September 1979 and amounted to 26.0% of the 26.6 kg produced by fry upstream. The estuarine production rate increased further to ~10.3 kg in 1980, comprising 38.0% of that recorded for stream fry notwithstanding the unusually high numbers inhabiting the stream in that year (20,953). These data demonstrate that even small estuaries can support important populations of rapidly growing coho. Increased growth in the estuary population was well illustrated by the observation that 50% of all fry that had inhabited the estuary from April/May to September were about as large as the one-year-old smolts leaving Carnation Creek for the sea in spring.

Physiological Acclimation to the Estuarine Environment

Coho fry leave the estuary with the onset of autumn freshets in late September-November. No overwintering occurs in the estuary, and only small numbers returned to fresh water to overwinter in a small tributary flowing into the intertidal zone of the stream at Carnation Creek. The overwinter survival rates of estuary fry leaving the intertidal zone in autumn have yet to be determined. However, laboratory and field studies in 1981-1982, together with the available literature, demonstrate that coho fry which emigrate from streams and reside in estuaries can (1) adapt physiologically to brackish estuarine waters during summer; (2) select salinities and temperatures within their ranges of preference and tolerance at which optima for survival, swimming activity, feeding, and growth are approached (Otto and McInerney, 1970); and, (3) acclimate temporally to waters of progressively higher salinity.

Samples of stream and estuary coho fry (N=10-12 each) collected monthly (May to November) and tested for salinity tolerance showed marked seasonal differences in their abilities to osmoregulate when immersed for 72 hours in brackish (15 ‰,) water or 24 hours in high-salinity (30 ‰,) water at 15°C in the laboratory.

Osmoregulatory perfomance in coho fry was determined by the concentration of sodium ions (Na^+) in their blood plasma. Juvenile coho in fresh water, and smolts in sea water, are able to maintain their plasma Na^+ concentrations 170 mM. Early in the season, neither stream nor estuary fry of equal (or near equal) body length and weight could osmoregulate fully in 15 ‰, brackish water (a salinity level slightly higher than that found on average in the estuary at high tide). From May to July, mean sodium ion concentrations ranged between ~177-182 and 183-188 mM in the plasma of estuary and stream fry respectively. However, a consistent trend for lower Na^+ concentrations in estuary fry became statistically significant by August (analysis of variance, Student's t; $p < 0.05$). From August to October/November, estuary coho maintained their plasma Na^+ concentrations ≤170 mM, eventually osmoregulating at a level statistically equal ($p > 0.05$) to that of control fry in fresh water.

Unlike estuary coho, stream fry never previously exposed to saline water were unable to achieve similarly low levels of plasma sodium between mid-summer and autumn, notwithstanding a progressive, growth-associated trend toward lower levels which culminated seasonally in a mean of ~179 mM in early November.

These tests on coho fry revealed that (1) complete adaptation to brackish water in "pre-smolt" estuary coho is a gradual process which can be apparent midway through their first summer of growth; (2) estuary fry are able to physiologically regulate their plasma Na^+ concentrations when immersed aburptly into brackish water after they have achieved this seasonal acclimation in their environment; and, (3) regardless of body size, short-term (72 h) adaptation is not possible at any time during summer in fry not previously exposed to brackish water. Moreover, the high survival rates of all experimental fry (no mortality in estuary coho, and only 1.4% in stream fry) show clearly that stream coho displaced into estuaries at any time are able to withstand at least 15 ‰ brackish water without incurring high mortality due to osmoregulatory failure. Moderately elevated plasma Na^+ levels did not impair the swimming or feeding activities in experimental coho in any obvious way. After entering estuaries, steam coho require a long-term period (e.g. > 30 days; Otto, 1971) to adapt fully to the salinity regime of the upper estuary.

The temporal development of mechanisms imparting tolerance to brackish water in estuary coho also resulted in seasonally increased tolerance to 30 ‰ sea water in that population. Estuary fry immersed in high-salinity water were able to progressively reduce their plasma Na^+ concentrations from spring to autumn ($p < 0.05$) and maintained significantly lower levels than stream fry by August. These trends notwithstanding, at no time between spring and autumn were estuary fry able to osmoregulate fully in 30 °/₀₀ sea water: their plasma Na^+ concentrations were always ≥186 mM on average. However, swimming and feeding activities appeared unchanged from the controls and mortality was only 1.4%.

In contrast with estuary fry, about 12% mortality was observed in stream coho immersed in 30 °/₀₀ sea water. Sodium ion concentrations in the plasma of stream fry never decreased below 200 mM on average.

Estuary fry apparently developed their ability to osmoregulate in brackish water and survive in sea water as a consequence of long-term exposure to intermediate-range salinities occurring intertidally. Although the smolt-sized fry leaving the Carnation Creek estuary in autumn were unable to fully osmoregulate in 30 °/₀₀ sea water, other tests demonstrated that these fry were able to maintain plasma Na^+ concentrations in water of 26 °/₀₀, salinity that were statistically equal to levels measured in fish held in15 °/₀₀ water. Therefore, it is concluded that coho fry leaving the estuary in autumn are able to physiologically tolerate the brackish conditions of the near-shore, surface waters of (for example) Barkley Sound over winter.

The capability of coho fry to devleop salinity resistance early in their life history is widespread in light of observations consistent among many different investigations, and is confirmed by the uniformity of the present experimental data both between years and among samples of coho collected from Carnation Creek and the Goldstream and Big Qualicum Rivers on Vancouver Island (Tschaplinski, 1982, 1987). Rapid growth and long-term exposure to water of intermediate-range salinity have both been identified as agents promoting salinity adaptation in coho fry (see Clarke et al., 1981, Conte et al., 1966). The present results are thus consistent with those of several other laboratory investigations which have shown that coho fry removed from fresh water, and reared for long periods in water of low or intermediate salinity, increase their tolerance to sea water at least six to seven months before they demonstrate the morphological and behavioral changes associated with the smolt transformation (Clarke et al., 1978, Conte et al., 1966).

Numerious studies have shown that coho fry reared in laboratory conditions where growth, salinities, temperatures, and photoperiods are variously optimized can transform into smolts in as few as 12 weeks (see Clarke et al. 1978, Folmar and Dickhoff, 1980). Furthermore, fry raised in estuarine impoundments under natural conditions can grow rapidly and can transform into smolts in only 90 days (Garrison, 1965). These smolts have been shown to return to their watershed as adults after spending a two-year period in the ocean.

Such studies demonstrate unequivocally that estuaries are not physiologically hostile environments for coho fry, and have important and direct implications for the conservation and artifical culture of estuary populations. The strong, positive relationship between growth rates and acclimation to sea water infers that rapid growth in estuary fry at Carnation Creek was at least partly responsible for their acclimation to 15 °/₀₀, brackish water and concurrently improved osmoregulation in 30 °/₀₀ sea water. Conversely, slow growth in stream fry may have impeded their seasonal acclimation to brackish water, and prevented any development of hypo-osmoregulation in sea water regardless of their lack of prior exposure to estuarine salminities. Several observations discounted the converse notion that the high rates of growth and production in estuary coho were caused by decreased metabolic costs of osmotic regulation in waters of low and intermediate salinity. Instead, all data indicated strongly that increased food abundance and availability in the estuary permitted the accelerated growth observed in emigrant fry.

Food Resources and Feeding Ecology of Stream and Estuary Coho

Increased growth efficiencies due to temperature optima could not be invoked to explain the large differences between the growth rates of stream and estuary coho at Carnation Creek because (a) the means and ranges in daily and seasonal water temperature were similar between the two environments; and, (b) coho growth in nature at temperatures between 5-17°C depends largely upon food abundance (see Averett, 1969). Additionally, experiments with coho fry in the laboratory have shown that potential increases in growth efficiencies in brackish waters resulting from decreased costs of osmotic regulation can account for < 10% of the increased growth in esutary fry during April-September at salinities measured in the upper estuary at Carnation Creek (Canagaratnam, 1959, Otto, 1971).

High environmental productivity ultimately caused increased rates of growth, production, and biomass-energy turnover in estuary coho compared with their stream-dwelling counterparts (Tschaplinski, 1987). Primary production alone is several times greater in the estuary than in the stream (Stockner and Shortreed, 1976). Additionally, production based on detrital food webs dominates over primary production in many shallow-water estuaries (Odum, 1980). The large populations of benthic macroinvertebrates supported by these webs are in turn the chief foods of fish predators incuding young coho.

All of the food organisms potentially available (Hyatt, 1979) to estuarine fry were numerically more abundant ($p < 0.05$) than those available to stream-dwelling coho at Carnation Creek between spring and autumn when fish grow the most rapidly. Benthic invertebrates alone were 6-6.5-fold more abundant monthly and annually in the estuary. Numbers in that environment ranged on average between 46,222 - 61,755 invertebrates/m^2 while only 7,140-11,387 invertebrates/m^2 were quantified from reaches upstream between June 1979 and late September 1980 (Table 1).

Similarly, invertebrate drift rates in the estuary exceeded those in the stream by wide margins (3-6 fold) diurnally except during freshetts (Figure 1). Aquatic (drifting benthic species) and terrestrial drift components were respectively 2-6-fold and 4-6-fold more abundant in the estuary in six of eight monthly studies conducted from July 1979 to May 1981 (Figure 1). Stream drift rates rose to equal those occurring intertidally only when discharge volumes were high in the watershed.

Although stream drift was sampled over complete diel cycles, that collected "diurnally" between 03:00-21:00 hours was concluded to best represent the potential drift prey of coho in the Carnation Creek system. Coho were primarily diurnal and crepuscular predators and ate few prey at night. Therefore, nocturnal drift was largely unavailable to either stream or estuary coho and was excluded from comparisons of food abundance between environments.

The highest drift rates observed diurnally in both the estuary and stream occurred during twilight periods, and especially at dusk (Figure 1). However, high rates also occurred in the estuary in association with tidal cycling. Peak drift rates were always recorded intertidally in the 3-hour period immediately following a flood tide. Tidal currents and the turbulence associated with the mixing of fresh and saline waters likely disturbed the sediments and dislodged many macroinvertebrates from the benthos, causing them to drift when the tide receeded. Visual observations also disclosed that saline water stimulated swimming activity in some estuarine crustaceans. Consequently, estuary drift enumerated diurnally between 03:00-21:00 hours exceeded the total numbers drifting in the stream over entire diel periods by factors of 2-3.5 whenever streamflows were low and stable (see Figure 1).

Finally, terrestrial prey caught on sticky traps at the air-water interface of pools were ~2-4-fold more numerous intertidally than in the stream in six of the same eight monthly analyses in which drift was quantified (Figure 2). Most terrestrial prey were aerial insects which were especially active above the surfaces of pools during midday periods and at dusk when coho fed frequently. Diverse and abundant coniferous and deciduous vegetation surrounding the estuarine channels might have accounted for the high numbers of terrestrial insects sampled in that environment.

Diel and seasonal data on coho predation showed clearly that greater temporal availability of prey combined with greater prey abundance promoted (1) increased duirnal feeding activity in estuary coho which (2) ultimately resulted in increased food consumption and growth in that population compared with coho upstream. Stomach-content analyses demonstrated that estuary coho consumed diurnally 28-71% more prey than their stream-dwelling counterparts (Figure 3; $p < 0.05$). These data were substantiated unequivocally by direct observations of feeding behavior which showed that estuary fry fed more frequently than stream coho during most times of the day, and daily made upward of twice as many feeding movements.

Estuary coho ate significantly more prey than stream fry and yearlings in every analyses. Averaging the data for each diurnal study, the stomachs of estuary coho contained between 54.3 ± 7.5 to 65.2 ± 8.6

Table 1. Comparative numbers of benthic macroinvertebrates in the stream and estuary at Carnation Creek during "summer" in 1979 and 1980. Means for each period were determined from eight bottom samples collected from riffles near the 100-m and 950-m sites in the stream and from sections 5 and 8 in the

STREAM		ESTUARY	
1979		1979	
Date	Numbers/m²	Date	Numbers/m²
30 June	7 140 ± 835	30 June	57 388 ± 5 064
17 September	10 012 ± 991	17 September	59 608 ± 5 395
1980		1980	
10 May	11 387 ± 2 635	10 May	46 222 ± 7 577
26 June	8 086 ± 2 277	17 June	53 454 ± 11 085
27 September	9 537 ± 2 352	27 September	61 755 ± 10 820

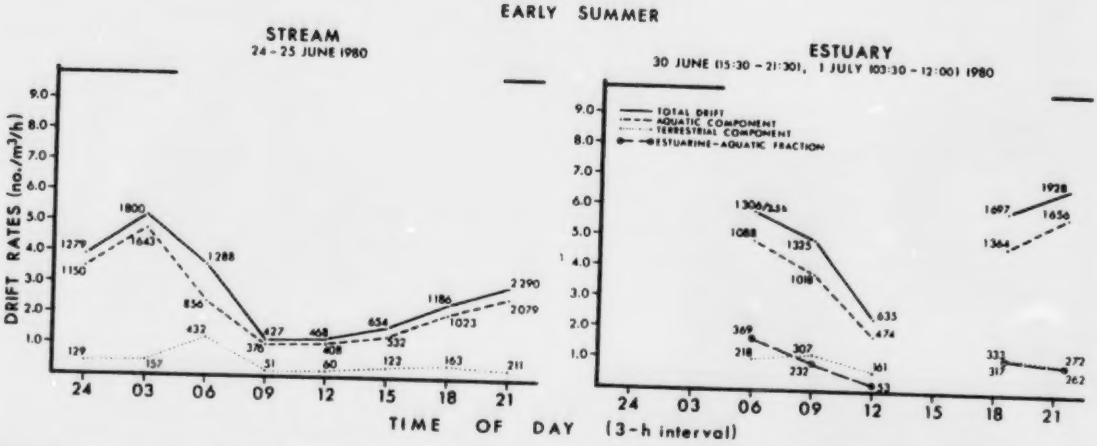

Figure 1. Comparative drift rates for the stream and estuary at Carnation Creek. High tides prevented continuous sampling in the estuary; however,diurnal rates (03:00-21:00 h) in the estuary, for the month exemplified here, exceeded those in the stream by factors of 1.6-4.3 over all 3-hour intervals (Mann-Whitney U, $p < 0.05$). Numbers of prey captured in each sample are also given.

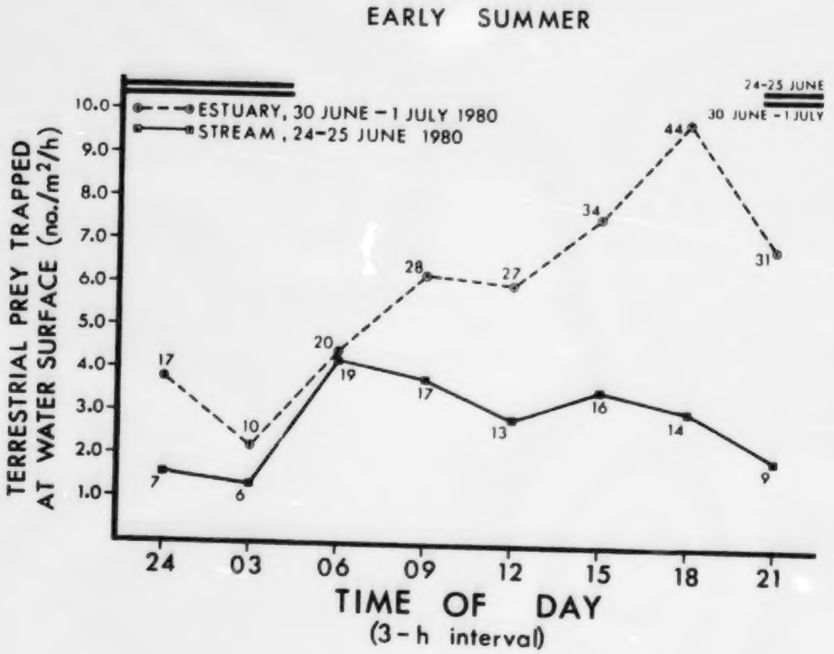

Figure 2. Comparative numbers of terrestrial invertebrates trapped at the air-water inteface in the stream and estuary at Carnation Creek. Estuary capture rates (no./m^2•h) and numbers for the period exemplified here, exceeded those in the stream by factors of 1.1-3.5 depending on each 3-hour sample (Mann-Whitney U, $p < 0.05$).

prey/fish•3h (Figure 3). In comparison, stream-dwelling salmon consumed only 34.0 ± 5.3 to 42.4 ± 8.4 prey/fish•3h throughout the day.

Temporal analyses of drift abundance and coho diet, combined with direct observations of feeding behavior, revealed that drifting invertebrates represented the most important immediate source of prey for stream and estuary juveniles. These studies showed that (1) most of the prey coho consumed originated from the drift, and (2) the diurnal feeding patterns of stream and estuary coho were linked closely to the temporal availability of drifting invertebrates. Estuary fry (and yearlings) consumed more prey than did stream coho because they had more opportunities to feed upon drift at all times of the day except at dusk.

Drift was generally less available to stream coho because maximum drift rates occurred nocturnally in that environment – from 33-61% of all stream drift sampled over 24 hours was collected at 24:00 and 03:00 h when coho were unable to feed upon it. Consequently, stream coho were limited to feeding intensively mainly at dusk when drift was the most abundant during daylight hours. Stream coho collected at 18:00 and 21:00 h consumed between 32.5 ± 10.7 to 79.0 ± 27.9 prey/fish•3h seasonally. Feeding frequencies were lower and relatively uniform at most other times of the day when stream fry and yearlings sometimes consumed as few as ~14 prey/fish•3h.

In contrast to the stream, estuary drift was especially abundant diurnally due to tidal cycling. Maximum drift rates, feeding activity, and food consumption were always temporally coincident and associated with tidal currents irrespective of time. Food consumption in estuary coho increased abruptly during flooding and high tides and peaked in the 3-hour period immediately following a tidal maximum (Figure 3). High predation rates during receding tides when drift rates were maximal accounted statistically for all differences in food consumption observed between stream and estuary coho in all months but one. Estuary coho sampled during periods of rapidly receding tide had consumed as many as 75.3 ± 18.9 prey/fish•3h at the same time that stream coho fed

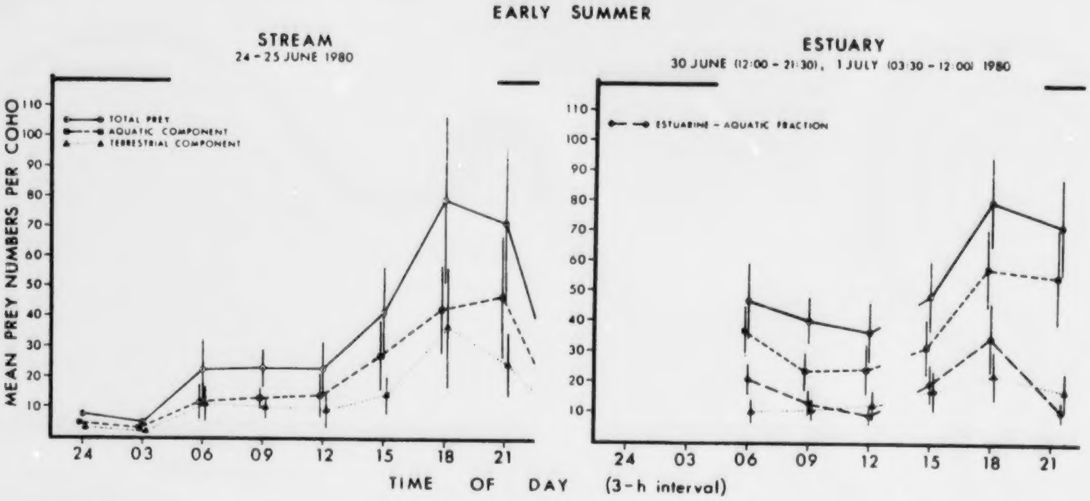

Figure 3. Numbers of prey contained within the stomachs of stream and estuary coho. High tides interrupted continuous sampling in the estuary; however, in the example given, estuary coho diurnally contained on average 54.3 ± 6.5 prey/fish•3h while similar-sized stream coho contained only 42.4 ± 8.4 prey/fish•3h ($p < 0.05$). All means include 95% confidence limits.

moderately or infrequently. Direct observations of feeding behavior corroborated these data by showing that coho feeding activity was significantly elevated by tidal cycling. The numbers of feeding movements made by estuary coho during periods of flooding/high tide and during the first hour of the receding tide exceeded those made simultaneously by stream coho by 3.6 fold on average (see Tschaplinski, 1987).

Increased feeding activity in estuary coho was not due solely to increased availability of drifting prey. Estuary juveniles were also able to feed directly upon the benthos, especially during periods of flooding and high tide. Stream coho directed < 4% of their daily feeding movements toward epibenthic prey. On the other hand, estuary fry at the same time made upward of 17% of their feeding movements toward the benthos. Moreover, one-half of all the feeding activity of estuary coho on two occasions was directed benthically during brief periods of flooding and high tide when saline water intruded over the sediments. Coho in the estuary were thus able to feed directly upon the most abundant prey occurring in the Carnation Creek watershed whereas benthic invertebrates were spatially unavailable to stream fry and yearlings.

Quantitative comparisons between the species proportions of the coho diet and those of drift, benthic, and surface-trap samples revealed that the greatest amount of overlap occurred consistently between the diet and drift in both the stream and estuary. The index of Moriseta (1959), modified by Horn (1966), demonstrated that "significant" overlap ($C_{\lambda} \geq 0.6$) occurred in each monthly comparison of diet and drift, and confirmed other data showing that drifting invertebrates were the most important immediate source of prey for stream-dwelling and estuarine juveniles (Table 2). Only the drift contained both aquatic and terrestrial invertebrates which together comprised the broad prey specturm of stream and estuary populations. Both the benthos and surface-trap samples thus lacked an important food component used regularly by young coho.

Table 2. Values of the index of Moriseta (1959) modified by Horn (1966) measuring the overlap (C_λ) between the taxonomic composition of prey found in coho stomachs with the overall taxonomic composition of prey sampled from the drift, benthos, and air-water interface. Overlap values range from 0 to 1. By convention, values > 0.6 are considered to represent "substantial" overlap.

Environment	Date	Drifting Prey	Benthic Prey	Terrestrial Prey at Air-Water Interface
Stream	1-2 May 1981	0.82	0.55	0.27
	28-29 May 1980	0.86	0.44	0.21
	24-25 June 1980	0.59	0.48	0.32
	23-24 July 1980	0.90	0.46	0.24
	6-7 October 1980	0.95	0.65	0.20
Estuary	1-2 May 1981	0.80	0.40	0.47
	28 May - 7 June 1980	0.80	0.66	0.43
	30 June - 1 July 1980	0.82	0.81	0.18
	29-30 July 1980	0.87	0.89	0.03
	18/23 September 1980	0.77	0.67	0.18

Seasonally, C_λ values for correlations between drift and diet ranged from 0.77 to 0.87 in the estuary, and between 0.59 and 0.95 in the stream. Correlations between coho diet and benthos showed that overlap was usually limited in the stream (C_λ = 0.44-0.55) except in autumn when an overlap of 0.65 was observed (Table 2). However, the significant overlap occurring in October did not reflect direct predation upon the benthos because stream coho made few benthic feeding movements. Instead, the increased overlap was due to (a) the similarity between the taxonomic composition of the benthos and the aquatic component of the stream drift, and (b) the low numbers of terrestrial insects available in the drift in autumn.

In contrast with the stream, substantial overlap occurred between the composition of the coho diet and estuary benthos in most analyses (Table 2). Overlap values for 1980 ranged between 0.66-0.89 and resembled those determined between the diet and drift. Although the taxonomic composition of the estuary benthos corresponded closely to that of the drift, the high overlap between coho diet and benthos was caused partly by coho feeding directly on the bottom fauna in that environment.

The least amount of overlap between any food source and the coho diet was observed for terrestrial prey caught on sticky traps at the air-water interface (Table 2). Overlap was uniformly low in all months in the stream, ranging seasonally between 0.20-0.32. In the estuary, overlap coefficients fell to as low as 0.18-0.03 from mid-to-late summer. All observations suggested that neither fry nor yearlings were able to capture the numerous, large-sized aerial insects which were active just above the surfaces of pools. Although these insects were abundant and contacted pool surfaces frequently, both stream and estuary coho captured most of their terrestrial prey from the drift.

The diets of stream and estuary coho were highly varied and included almost all of the species identified from benthic, drift, and surface-trap samples. Over 340 prey categories including the larvae, pupae, and adults of numerous insect species were consumed by coho in both environments. Most taxa, especially terrestrial species, weere eaten in small numbers, and many occurred sporadically in both the coho diet and environmental samples throughout the season. Only 26 species in the stream and 30 in the estuary each formed at least one percent of the coho diet in the respective environments in any of the monthly studies. All prey important in the coho diet were also present in drift samples in similar or identical numerical rankings (Tschaplinski, 1987). Because coho appeared to feed expediently on the most abundant prey items and usually did not differentiate between species, the diets of stream and estuary coho were described and analyzed seasonally after combining most prey species and genera into common families or even broader taxonomic categories (Tables 3, 4).

Ranked numerically in descending order, the insect orders Diptera (flies), Ephemeroptera (mayflies), Collembola (springtails), Plecoptera (stoneflies), and Trichoptera (caddisflies) collectively formed 89% of the prey of stream coho at all times. The Diptera, consisting of both aquatic (larvae and pupae), and terrestrial life stages (mainly aerial adults) together composed 48% of the coho diet numerically, 30% of it by volume, and 39% by IRI in mid-summer (Tschaplinkski, 1987).

The Chironomidae were by far the most abundant dipterans in the stream benthos and drift, and in turn this family was the most important one used for food by stream coho. Seven principal species plus numerious rare ones together formed 28-44% of the coho diet monthly. Aquatic larvae and pupae composed respectively 10-20 and 1-9% of the diet of stream fry and yearlings, while aerial adults simultaneously formed 10-16% throughout the season.

Mayfly nymphs were the most common aquatic prey of stream coho by all measures, forming 14-37% of the diet monthly. The Baetidae (mainly *Baetis tricaudatus*) which formed 5-28% of the diet, and *Paraleptophlebia sp.* (Leptophlebiidae) which composed 1-15% of all items counted from the stomachs of stream coho, were the dominant mayflies in all months. Additionally, *Ameletus* sp (Siphlonuridae) was consumed in substantial numbers when it was available in the drift in spring (Table 3).

Other prey formed important fractions fo the coho diet when they were available in the drift. For example, stonefly nymphs (mainly *Alloperla sp.* group), which were abundant benthically but usually present in the drift and diet in low or moderate numbers, composed 16% of diet numerically in early spring at the same time that they formed 12% of the stream drift.

Like their stream-dwelling counterparts, estuary coho fed opportunistically on any available invertebrate prey. However, only two invertebrate orders, the Diptera and Amphipoda, together formed 61-89% of the diet of estuary fry in both 1980 and 1981 (Table 4). The Diptera alone were overwhelmingly the most important food source of estuary coho, forming upward of 61% of the diet numerically, 34% of it by volume, and 52% by IRI. In turn, most dipterans were aquatic and aerial chironomids. Collectively, chironomids formed 31-51% of the coho diet monthly (Table 4). Aquatic larvae and pupae composed respectively 8-35 and 3-10% of the prey consumed by estuary fry and yearlings throughout the study, while aerial adults simultaneously formed 9-21% of their diet.

All data lead to the conclusion that juvenile coho are generalist predators, readily able to feed upon whatever prey was spatially or temporally available. Generalized feeding habits allowed emigrant coho from the stream to adapt to most prey species occurring intertidally. Consequently, "estuarine-aquatic" species consisting mainly of intertidal crustaceans (amphipods and isopods) formed 30-33% of the coho diet monthly in 1980. These percentages were extraordinarily invariant throughout the season and indicated clearly that coho fry were able to prey effectively upon estuarine invertebrates soon after emigrating from the stream regardless of the complex salinity and temperatures regimes occurring intertidally. Estuarine-aquatic species formed 39-50% of the benthic fauna and ~15-23% of the drift monthly; therefore, coho fed upon them efficiently in amounts equalling or exceeding the proportions composed by these species in environmental samples.

Corophium spinicorn (Corophiidae) and *Eogammarus confervicolus* were the two estuarine-aquatic species most frequently used for food by juvenile coho. *Corophium*, a tube-dwelling amphipod, was seasonally the most important prey species in the estuary, forming 19-24% of all prey which coho consumed in 1980. In comparison, the amphipod *E. confervicolus* composed numerically 5-13% of the coho diet throughout the study. The isopod *Gnorimosphaeroma oregonense* made up the remainder of the estuarine-aquatic prey consumed by coho fry and yearlings (Table 4).

The diets of juvenile coho salmon in both the stream and estuary at Carnation Creek remained largely

Table 3a. Seasonal prey of juvenile coho salmon in Carnation Creek. Prey items are ranked by percent numerical abundance. Statistics were determined from samples of coho collected at 3-hour intervals between 06:00 and 21:00 h. Each sample consisted of 10-12 coho. All prey numbers were determined from pooled data. Most prey items are given at the family level and most taxa comprising <1% of the diet are omitted. Only major genera and species are listed below (L = larvae, P = pupae, N = nymphs, A = adults, AQ = aquatic, T = terrestrial).

	1-2 MAY 1981		28-29 MAY 1980		24-25 JUNE 1980		23-24 JULY 1980		6-7 OCTOBER 1980	
TAXON	Numbers	Percent of Total	Numbers	Percent of Total	Numbers	Percent of Total	Numbers	Percent of Total	Numbers	Percent of Total
COPEPODA: Cyclopoida: Cyclopidae: *Eucyclops serrulatus* (AQ)	0	0	6	0.2	0	0	5	0.2	11	0.5
Harpacticoida: Canthocamptidae: *Bryocamptus* (2 spp.) (AQ)	0	0	5	0.2	2	0.1	22	0.9	14	0.7
ARACHNIDA: ACARINA: (A) Trombidiformes (All; AQ)	43	1.9	272	10.4	102	3.7	123	5.0	94	4.6
1. Hygrobatidae (2 spp.)	16	0.7	34	1.3	8	0.3	25	1.0	15	0.7
2. Arrenuridae: *Arrenurus* sp.	11	0.5	126	4.8	80	2.9	14	0.6	0	0
3. Torrenticolidae (2 spp., mainly *Torrenticola* sp.)	9	0.4	77	2.9	9	0.3	44	1.8	56	2.8
4. Aturidae: *Aturus* sp.	1	< 0.1	18	0.7	0	0	17	0.7	9	0.4
(B) Oribatei (All; AQ/T)	14	0.6	15	0.6	8	0.3	11	0.4	12	0.6
(C) Others (Prostigmata, Astigmata, Mesostigmata)	7	0.3	7	0.3	1	< 0.1	3	0.1	8	0.4
INSECTA: (A) Collembola (All; AQ/T)	135	6.0	221	8.4	326	11.9	257	10.4	82	4.0
1. Hypogastruridae	38	1.7	53	2.0	135	4.9	88	3.6	7	0.3
2. Isotomidae	42	1.9	31	1.2	75	2.7	67	2.7	51	2.5
3. Sminthuridae	53	2.3	137	5.2	104	3.8	96	3.9	24	1.2
(B) Ephemeroptera (All, A/N)	584	25.8	373	14.3	656	23.8	683	27.6	760	37.3
Nymphs (AQ)	578	25.6	361	13.8	643	23.4	675	27.3	757	37.1
1. Baetidae (N; 4 spp., mainly *Baetis* 3 spp.)	203	9.0	278	10.6	134	4.8	348	14.1	568	27.9
2. Siphlonuridae (N; mainly *Ameletus* sp.)	130	5.8	37	1.4	41	1.5	16	0.7	9	0.4
3. Heptageniidae (N; All)	56	2.5	30	1.2	61	2.2	79	3.2	17	0.8
(a) *Cinygmula reticulata* and C. *ramaleyi*	17	0.8	8	0.3	29	1.1	56	2.3	16	0.8
(b) *Epeorus* (*Iron*) sp.	39	1.7	22	0.8	25	0.9	23	0.9	1	0.1
4. Leptophlebiidae: *Paraleptophlebia* (2 spp.; N)	133	5.9	16	0.6	402	14.6	232	9.4	163	8.0
(C) Plecoptera (All, A/N)	357	15.8	24	0.9	95	3.5	84	3.4	110	5.4
Nymphs (AQ)	353	15.6	24	0.9	95	3.5	84	3.4	110	5.4
1. Chloroperlidae (N; 3 spp.)	291	12.9	24	0.9	92	3.4	77	3.1	92	4.5
(a) *Alloperla* sp. grp.	225	10.0	21	0.8	82	3.0	73	3.0	67	3.3
(b) *Kathcoperla perdita*	66	2.9	3	0.1	8	0.3	4	0.2	25	1.2
2. Leuctridae: *Leuctra* sp. grp.	57	2.4	0	0	0	0	7	0.3	0	0
(D) Psocoptera (A/N, T; 2 fam., 2 spp.)	15	0.7	39	1.5	30	1.1	43	1.7	18	0.9

Table 3b. Seasonal prey of juvenile coho salmon in Carnation Creek. Prey items are ranked by percent numerical abundance. Statistics were determined from samples of coho collected at 3-hour intervals between 06:00 and 21:00 h. Each sample consisted of 10-12 coho. All prey numbers were determined from pooled data. Most prey items are given at the family level and most taxa comprising <1% of the diet are omitted. Only major genera and species are listed below (L = larvae, P = pupae, N = nymphs, A = adults, AQ = aquatic, T = terrestrial).

TAXON	1-2 MAY 1981		28-29 MAY 1980		24-25 JUNE 1980		23-24 JULY 1980		6-7 OCTOBER 1980	
	Numbers	Percent of Total	Numbers	Percent of Total	Numbers	Percent of Total	Numbers	Percent of Total	Numbers	Percent of Total
(E) Hemiptera (A/N, T; 11 spp.)	4	0.2	1	< 0.1	0	0	6	0.2	0	0
(F) Homoptera (A/N, T; mainly Aphididae; 12 spp.)	19	0.8	5	0.2	12	0.4	24	1.0	6	0.3
(G) Coleoptera (A/L; AQ/T)	27	1.2	22	0.8	49	1.8	47	1.9	31	1.5
(H) Trichoptera (All; L/P/A)	12	0.5	38	1.5	89	3.2	61	2.5	36	1.8
Larvae and pupae (AQ)	12	0.5	38	1.5	86	3.1	61	2.5	36	1.8
1. Limnephilidae (7 spp.)	3	0.1	6	0.2	25	0.9	19	0.8	5	0.3
2. Hydroptilidae (Agraylea sp.)	5	0.2	9	0.3	22	0.8	13	0.5	0	0
(I) Diptera: 1. Dixidae: Dixella sp. (L/P, AQ)	0	0	8	0.3	18	0.7	13	0.5	2	0.1
2. Ceratopogonidae (All; 14 spp.)	138	6.1	147	5.6	233	8.5	135	5.5	5	0.3
(a) larvae (AQ)	25	1.1	4	0.2	14	0.5	7	0.3	0	0
(b) pupae/emerging adults (AQ)	17	0.8	0	0	18	0.7	20	0.8	0	0
(c) adults (T)	96	4.2	143	5.5	201	7.3	108	4.4	5	0.3
3. Chironomidae (All; 31 spp.)	699	30.9	1 163	44.4	766	27.8	723	29.2	686	33.7
(a) larvae (AQ)	223	9.9	511	19.5	337	12.3	271	11.0	416	20.4
(b) pupae/emerging adults (AQ)	171	7.6	229	8.8	21	0.8	122	4.9	74	3.6
(c) adults (T)	305	13.5	423	16.2	408	14.8	330	13.3	196	9.6
4. Simuliidae (L/P/A; AQ/T; mainly Simulium sp.)	21	0.9	37	1.4	21	1.1	12	0.5	8	0.4
5. Sciaridae (A,T; 6 spp.)	33	1.5	25	1.0	74	1.6	44	1.8	20	1.0
6. Cecidomyiidae (A/L; T; 9 spp.)	64	2.8	59	2.3	119	4.3	87	3.5	35	1.7
7. Empididae (L, P, A; AQ/T; 12 spp.)	15	0.7	48	1.8	41	1.5	36	1.5	22	1.1
(J) Hymenoptera (A, T; 15 fam., > 20 spp.)	36	1.6	51	2.0	30	1.1	49	2.0	34	1.7
Total Aquatic Prey	1 559	68.9	1 669	63.8	1 635	59.4	1 602	64.7	1 592	78.1
Total Terrestrial Prey	703	31.1	949	36.3	1 119	40.6	873	35.3	446	21.9
Number of Coho in Sample	60		65		65		65		60	

Table 4a. Seasonal prey of juvenile coho salmon in the Carnation Creek estuary. Prey items are ranked by percent numerical abundance. Statistics were determined from samples of coho collected at 3-hour intervals between 06:00 and 21:00 h. Each sample consisted of 8-12 coho. All prey numbers were determined from pooled data. Only major genera and species are listed below. (L = larvae, P = pupae, N = nymphs, A = adults, AQ = aquatic, AQ-MAR = "marine" or estuarine-aquatic, T = terrestrial).

TAXON	1-2 MAY 1981		28 MAY-7 JUNE 1980		30 JUNE-1 JULY 1980		29-30 JULY 1980		18-23 SEPTEMBER 1980	
	Numbers	Percent of Total	Numbers	Percent of Total	Numbers	Percent of Total	Numbers	Percent of Total	Numbers	Percent of Total
ANNELIDA: POLYCHAETA: Nereidae: *Nereis* (2 spp.; AQ-MAR)	3	0.1	11	0.3	8	0.3	7	0.2	13	0.4
OLIGOCHAETA: Enchytraeidae (AQ)	15	0.5	3	0.1	10	0.3	2	0.1	11	0.3
COPEPODA: Cyclopoida: Cyclopidae: *Eucyclops serrulatus* (AQ)	10	0.3	0	0	3	0.1	1	< 0.1	4	0.1
Harpacticoida: Canthocamptidae: *Bryocamptus* (2 spp., AQ)	0	0	42	1.3	28	0.9	38	1.1	2	0.1
Harpacticidae: *Harpacticus uniremis* (AQ-MAR)	4	0.1	9	0.3	29	1.0	50	1.4	27	0.8
ISOPODA: Sphaeromatidae: *Gnorimosphaeroma oregonense* (AQ-MAR)	7	0.2	12	0.4	95	3.1	177	4.9	148	4.5
AMPHIPODA: 1. Anisogammaridae: *Eogammarus confervicolus* (AQ-MAR)	426	13.4	173	5.1	241	7.9	189	5.3	150	4.6
2. Corophiidae: *Corophium spinicorne* (AQ-MAR)	134	4.2	811	24.1	625	20.6	673	18.8	744	22.8
ARACHNIDA: ACARINA: (A) Trombidiformes (All; 9 fam., 13 spp.)	97	3.1	27	0.8	21	0.7	16	0.5	14	0.5
(B) Oribatei (All, AQ/T)	26	0.8	8	0.2	11	0.4	22	0.6	17	0.5
(C) others (Prostigmata, Astigmata, Mesostigmata)	17	0.5	3	0.1	3	0.2	13	0.4	4	0.1
INSECTA: (A) Collembola (All; AQ/T)	285	9.0	14	0.4	184	6.1	281	7.8	375	11.5
1. Hypogastruridae	96	3.1	10	0.3	46	1.5	57	1.6	104	3.2
2. Isotomidae	122	3.9	3	0.1	79	2.6	100	2.8	67	2.1
3. Sminthuridae	67	2.1	1	< 0.1	59	1.9	124	3.5	202	6.2
(B) Ephemeroptera (All; A/N)	244	7.7	14	0.4	0	0	2	0.1	7	0.2
Nymphs (AQ)	236	7.4	14	0.4	0	0	2	0.1	7	0.2
1. Baetidae (N; *Baetis* 2 spp.)	111	3.5	12	0.4	0	0	2	0.1	0	0
2. Siphlonuridae: *Ameletus* sp. (N)	39	1.2	2	0.1	0	0	0	0	0	0
3. Heptageniidae: *Cinygmula reticulata* and C. *ramaleyi*(N)	33	1.0	0	0	0	0	0	0	0	0
4. Leptophlebiidae: *Paraleptophlebia* (2 spp.; N)	53	1.7	0	0	0	0	0	0	7	0.2

Table 4b. Seasonal prey of juvenile coho salmon in the Carnation Creek estuary. Prey items are ranked by percent numerical abundance. Statistics were determined from samples of coho collected at 3-hour intervals between 06:00 and 21:00 h. Each sample consisted of 8-12 coho. All prey numbers were determined from pooled data. Only major genera and species are listed below. (L = larvae, P = pupae, N = nymphs, A = adults, AQ = aquatic, AQ-MAR = "marine" or estuarine-aquatic, T = terrestrial).

	1-2 MAY 1981		28 MAY-7 JUNE 1980		30 JUNE-1 JULY 1980		29-30 JULY 1980		18-23 SEPTEMBER 1980	
TAXON	Numbers	Percent of Total	Numbers	Percent of Total	Numbers	Percent of Total	Numbers	Percent of Total	Numbers	Percent of Total
(C) Plecoptera (All; A/N)	77	2.4	12	0.4	7	0.2	6	0.2	9	0.3
Nymphs (AQ)	68	2.1	12	0.4	7	0.2	6	0.2	9	0.3
1. Chloroperlidae (N; 3 spp.)	40	1.3	12	0.4	5	0.2	1	< 0.1	9	0.3
(a) *Alloperla* sp. grp.	40	1.3	12	0.4	5	0.2	1	< 0.1	9	0.3
2. Leuctridae: *Leuctra* sp. grp.	28	0.9	0	0	2	0.1	5	0.1	0	0
(D) Psocoptera (A/N, T; 2 fam., 2 spp.)	42	1.3	8	0.2	18	0.6	30	0.8	61	1.9
(E) Thysanoptera: Aeolothripidae: *Aeolothrips annectens* (A/N; T)	18	0.6	3	0.1	14	0.5	24	0.7	88	2.7
(F) Hemiptera (A/N, T; 5 fam., 6 spp.)	9	0.3	3	0.1	6	0.2	15	0.4	43	1.3
1. Miridae	9	0.3	2	0.1	6	0.2	14	0.4	43	1.3
(G) Homoptera (A/N, T; 5 fam., 10 spp.)	144	4.5	100	3.0	37	1.2	52	1.5	164	5.0
1. Aphididae (mainly *Aphis* sp. and *Macrosiphium* spp.)	140	4.4	92	2.7	37	1.2	50	1.4	157	4.8
(H) Coleoptera (A/L; AQ/T)	64	2.0	25	0.7	40	1.3	27	0.8	34	1.0
(I) Trichoptera (L; AQ)	8	0.3	5	0.2	2	0.1	3	0.1	0	0
(J) Diptera: 1. Ceratopogonidae (All; 12 spp.)	181	5.7	136	4.0	62	2.0	33	0.9	42	1.3
(a) larvae (AQ)	3	0.1	14	0.4	0	0	0	0	0	0
(b) pupae/emerging adults (AQ)	34	1.1	0	0	0	0	0	0	0	0
(c) adults (T)	144	4.5	122	3.6	62	2.0	33	0.9	42	1.3
2. Chironomidae (All; 28 spp.)	1 160	36.6	1 718	51.0	1 442	47.4	1 786	49.8	1 026	31.4
(a) larvae (AQ)	266	8.4	708	21.0	846	27.8	1 260	35.2	511	15.6
(b) pupae/emerging adults (AQ)	317	10.0	296	8.8	132	4.3	191	5.3	93	2.8
(c) adults (T)	577	18.2	714	21.2	464	15.3	335	9.3	418	12.8
3. Mycetophilidae (A, T; 5 spp.)	21	0.7	36	1.1	16	0.5	4	0.1	5	0.2
4. Sciaridae (A, T; 4 spp.)	47	1.5	15	0.5	23	0.8	10	0.3	8	0.2
5. Empididae (All; AQ/T; 12 spp.)	59	1.9	105	3.1	48	1.6	26	0.7	15	0.5
(a) pupae/emerging adults (mainly AQ)	4	0.1	56	1.7	10	0.3	0	0	3	0.1
(b) adults (T)	55	1.7	49	1.5	38	1.3	26	0.7	12	0.4
(K) Hymenoptera (A, T; 15 fam., 30 spp.)	40	1.3	31	0.9	38	1.3	67	1.9	208	6.4
1. Mymaridae	27	0.9	0	0	18	0.6	45	1.3	55	1.7
2. Pteromalidae	0	0	3	0.1	7	0.2	8	0.2	71	2.2
3. Platygasteridae	7	0.2	0	0	12	0.4	10	0.3	74	2.3
Total Aquatic Prey	1 856	58.5	2 246	66.7	2 209	72.6	2 752	76.8	1 868	57.1
Total "Marine" or Estuarine Prey	589	18.6	1 019	30.3	998	32.8	1 096	30.6	1 082	33.1
Total Terrestrial Prey	1 316	41.5	1 120	33.3	832	27.4	833	23.3	1 401	42.9
Number of Coho in Sample	60		55		56		55		60	

unchanged seasonally between May and September/October (Tables 3, 4). The ranking of the principal families, genera, and species in the diets of juvenile coho displayed no clear seasonal patterns in either environment; nevertheless, all monthly shifts in the species used for food conformed most closely with changing patterns of relative abundance of the same invertebrate taxa occurring in the drift.

Values of the Linear Index of Food Selection (L) applied to the same food categories used to describe the seasonal prey of stream and estuary coho revealed that the proportions of the coho diet formed by each prey taxon corresponded closely to the percentages these invertebrates formed in the drift. No selection values > -0.23 or +0.14 were determined for any estuary prey taxon between the coho diet and drift, and none occurred outside the range bounded by -0.21 and +0.15 in the stream (Tschaplinski, 1987). Therefore, most prey species were neither strongly preferred nor avoided by coho because most "L" values were close to zero in both environments (Tschaplinski, 1987). Stream and estuary coho were clearly feeding opportunistically upon most invertebrates in direct proportion to the numerical abundance these prey formed in drift samples.

Some taxa such as fish (or fish larvae) and oligochaete worms were nevertheless avoided by coho or unavailable to them, and were thus associated with negative (and significant) L values. At no time were Carnation Creek coho predators of other fish species. Additionally, several L values determined between the coho diet and benthic taxa were negative and significant in both environments (see Tschaplinski, 1987). This trend implies strongly that most invertebrates living within the benthic sediments were spatially unavailable to coho despite observations revealing that estuary fry fed frequently on the bottom fauna. Many benthic prey must first enter the drift before stream or estuary coho are able to use them for food.

The results of this investigation show emphatically that most species in the drift were available to stream and estuary coho. Given that (1) the potential prey of estuary coho were several fold more abundant than those available to coho upstream, and (2) aquatic drift abundance is partly a function of production rates in benthic invertebrate populations (Muller,1974), it is concluded that the ability of estuary coho to use most of these invertebrates in proportion to their abundance directly links the increased growth rates of estuary coho to the increased secondary productivity occurring in that environment compared to the stream.

Coho fry in the estuary were clearly not food limited. The late-summer population in 1980 was double that in 1979; however, estuary fry grew equally rapidly in the two years. Mean instantaneous growth rates (in length) in 1979 were 0.133 ± 0.029 (i.e. 13.3% per month), and were no less than 0.124 ± 0.012 in 1980 (Tschaplinksi, 1987). In comparison, mean monthly increments in the stream zone were only 0.084 and 0.064 in 1979 and 1980 respectively. Moreover, Holtby and Hartman (1982) reported that the instantaneous growth rates of stream coho were density-dependent during summer, and low rates in years such as 1980 were associated with populations that were unusually large. Low growth rates in the stream were also negatively correlated with the number and duration of minimum stream flows during summer (Holtby and Hartman, 1982), intimating strongly that reductions in the abundance and availability of drifting food organisms underlay poorer seasonal growth in stream-resident coho populations. Estuary food resources were sufficiently abundant that similar density-dependent growth reductions were not observed between years in that environment.

IMPLICATIONS FOR COHO MANAGEMENT, ENHANCEMENT AND PRESERVATION

Only limited numbers (300) of estuary coho fry leaving the watershed after their first summer of growth have presently been marked. Consequently, only small numbers (9) have been found to return to the watershed in subsequent years, and all returns have been jacks (small-sized, sexually mature males, < two years old). The numbers of estuary-reared juveniles returning to the watershed to spawn have yet to be determined accurately. Despite this limitation, this investigation has demonstrated that coho salmon fry occur naturally in estuaries, adapt readily to the physiological rigors and abundant food resources of the intertidal zones of streams, rapidly outgrow their stream-dwelling counterparts, and can contribute some spawners for the following generation.

Recent data from Porcupine Creek, Alaska has revealed that estuary-reared coho form upward of 30% of all coho rearing in that watershed and can comprise up to 50% of the adults returning to spawn (see Thedinga and Koski, 1984). The estuary at

Porcupine Creek forms only 27% of the total rearing habitat in that watershed. Small estuaries therefore appear to be potentially important rearing areas for coho fry as observed in several streams on Vancouver Island and elsewhere on the Pacific coast, and should be considered by biologists, fisheries managers, and land-use planners.

Data on estuary coho at Carnation Creek are unavailable for most of the years that the watershed has been studied. Therefore, the historical contribution that estuary coho have made toward both juvenile and adult populations is unknown but should not be discounted simply because the information has not been gathered. Population surveys have shown that most emigrant fry do not become established as estuary residents. Less than 23 and 9% of the total numbers leaving the stream in 1979 and 1980 respectively remained in the estuary by the end of summer. Although late-summer populations in the estuary amounted roughly to 10% of those upstream, there are several important implications for the use of estuaries as rearing areas for juvenile salmonids. In some watersheds, populations of large, rapidly-growing estuarine coho fry might (a) provide significant numbers of smolts to ocean-dwelling populations, especially in years when low numbers of smolts are produced upstream, and (b) augment the numbers of adults returning to the watershed to spawn. Additionally, all estuaries appear to provide salmonid smolts with a transition zone between freshwater and marine environments in which they may reside in deep pools for variable periods of time, complete the fry-smolt transformation, and acclimate to saline water.

With reference to habitat preservation, logging-related practices which may destroy or alter estuarine habitats should be avoided or minimized. Reducing the harmful effects of log storage, siltation, or the input of wood chips and other small debris, not only maintains the integrity of the structural habitats which coho require, but also is important to preserve the stability and composition of benthic substrates which support large populations of invertebrate food organisms. Similarly, deciduous and coniferous vegetation essential for stabilizing banks and providing shelter for coho must also be maintained to (1) provide leaves and other organic material as a source of energy for detritus-based food webs which lead to the production of benthic invertebrates, and (2) directly contribute terrestrial insects as a source of food.

Since 1981, the Carnation Creek estuary has supported few fry. Populations have been reduced by 90% or more compared to levels assessed in 1980. Habitat destruction is directly responsible for these reduced numbers. Sedimentation and gravel movements have filled in side channels or have isolated them from the main channel. Main-channel pools which contained most of the estuary fry have virtually been eliminated due to the same substrate movements. Severe freshets have (1) caused bank collapse, (2) swept away large debris essential for the reduction of water velocities, and (3) caused associated changes in substrate distribution. Because estuaries may receive the sum of logging-related effects occurring upstream in the watershed, substantial damage to estuarine habitats appears to have been caused after logging and can be related to similar processes of habitat destabilization occurring at sites in the stream.

Because the habitat requirements of stream and estuary coho are similar, and because many of the physical processes affecting stream populations ultimately extend downstream to the estuary, common practices can be employed in streams and estuaries to manage, preserve, and enhance their coho populations. Ensuring that sources of large, woody debris are available in both environments will preserve optimum habitats by creating pools and reducing water velocities. Stabilizing flow regimes will also ensure the availability of drifting food organisms for coho. Juvenile coho fed upon both aquatic and terrestrial invertebrates in direct proportion to their availability in the drift. Therefore, enhancing prey availability should increase coho growth rates and production. Management techniques designed to provide optimum conditions for coho growth must ensure that (1) benthic invertebrate production is maintained or enhanced, and (2) sources of terrestrial invertebrates are provided or conserved.

Estuary populations might be enhanced by excavating stable secondary channels alongside major estuarine reaches to provide more habitat space in order to retain larger numbers of spring emigrants intertidally throughout the summer.

The conditions necessary for benthic invertebrate production can be ensured by allowing both tidal and fresh water to enter the new channels. Other channels might also be excavated in areas remote from tidal influence in order to provide sheltered habitats which fry might use optionally for overwintering sites instead of moving seaward in autumn. The permanent weir at Carnation Creek might presently inhibit estuary fry from overwintering upstream, as most fry do in Porcupine Creek (Murphy et al. 1984). Nutrient enrichment or other methods for enhancing food production are likely inappropriate and unnecessary for both artificial and natural estuarine channels. High rates of primary and secondary production already occur in estuaries.

If enough space is available for constructing supplementary estuarine channels, complete with stabilized banks and shelter provided by large, woody debris (e.g., logs, fallen trees, root masses), coho production in small coastal watershed could be multiplied several fold without incurring the expenses required for nutrient addition or supplemental feeding.

Stream and estuary populations were considered separately, but may also be viewed as a single population of trophic generalists adapting behaviorally to feed upon different species of invertebrates in environments of contrasting salinities, flow patterns, food abundance, and prey availability. The seaward emigration of fry in spring does not have to be viewed as a disadvantage to juvenile coho. Rather, these movements can improve the feeding opportunities for coho fry and permit stream populations to disperse so that all habitats and food resources available in the watershed are fully used.

REFERENCES CITED

Au, D.W.K. 1972. Population dynamics of the coho salmon and its response to logging in three coastal streams. Ph.D. Thesis, Oregon State University, Corvallis, OR. 245 p.

Averett, R.C. 1969. Influence of temperature on energy and material utilization by juvenile coho salmon. Ph.D. Thesis, Oregon State University, Corvallis, OR. 74 p.

Canagaratnam, P. 1959. Growth rates of fishes in different salinities. J. Fish. Res. Board Can. 16: 121-130.

Clarke, W.C., J.E. Shelbourn, and J.R. Brett. 1978. Growth and adaptation to sea water in "underyearling" sockeye (*Oncorhynchus nerka*) and coho (*O. kisutch*) salmon subjected to regimes of constant or changing temperature and day length. Can. J. Zool. 56: 2413-2421.

Clarke, W.C., J.E. Shelbourn, and J.R. Brett. 1981. Effect of artificial photoperiod cycles, temperature, and salinity on growth and smolting in underyearling coho (*Oncorhynchus kisutch*), chinook (*O. tshawytscha*), and sockeye (*O. nerka*) salmon. Aquaculture 22: 105-116.

Conte, F.P., H.H. Wagner, J.C. Fessler, and C. Gnose. 1966. Development of osmotic and ionic regulation in juvenile coho salmon (*Oncorhynchus kisutch*). Comp. Biochem. Physiol. 18: 1-15.

Folmar, L.C. and W.W. Dickhoff. 1980. The parr-smolt transformation (smoltification) and seawater adaptation in salmonids. A review of selected literature. Aquaculture 21: 1-37.

Garrison, R.L. 1965. Coho salmon smolts in ninety days. Prog. Fish-Cult. 27: 219-220.

Heard, W.R. and R.A. Crone. 1976. Raising coho salmon from fry to smolts in estuarine pens, and returns of adults from two smolt releases. Prog. Fish-Cult. 38: 171-174.

Holtby, L.B. and G.F. Hartman. 1982. The population dynamics of coho salmon (*Oncorhynchus kisutch*) in a west coast rain forest stream subjected to logging. In Proceedings of the Carnation Creek workshop, A 10-year review. 24-26 February, 1982. Edited by G.F. Hartman. Pacific Biological Station, Nanaimo, B.C. pp. 308-347.

Horn, H.S. 1966. Measurement of "overlap" in comparative ecological studies. Am. Naturalist 100: 419-424.

Hyatt, K.D. 1979. Feeding strategy. In Fish physiology. Volume VIII. Edited by W.S. Hoar, D.J. Randall, and J.R. Brett. Academic Press. New York. pp. 71-119.

MacArthur, R.H. and R. Levins. 1967. The limiting similarity, convergence,and divergence of coexisting species. Am. Naturalist 101: 377-385.

Morisita, M. 1959. Measuring the interspecific association and similarity between communities. Memoirs of the Faculty of Science Kyushu University Series E (Biology) 3: 65-80.

Muller, K. 1974. Stream drift as a chronobiological phenomenon in running water ecosystems. Ann. Rev. Ecol. Syst. 5: 309-323.

Mundie, J.H. 1974. Optimization of the salmonid nursery stream. J. Fish. Res. Board Can. 31: 1827-1837.

Murphy, M.L., J.F. Thedinga, K.V. Koski and G.B. Grette. 1984. A stream ecosystem in an old-growth forest in southeast Alaska: Part V: Seasonal changes in habitat utilization by juvenile salmonids. In Fish and wildlife relationships in old-growth forests. Proceedings of a symposium held 12-15 April 1982, Juneau, Alaska. Edited by W.R. Meehan, T.R. Merrell Jr., and T.A. Hanley. American Institute of Fishery Research Biologists. pp. 89-98.

Odum, E.P. 1980. The status of three ecosystem-level hypotheses regarding salt marsh estuaries: tidal subsidy, outwelling, and detritus-based food chains. In Estuarine perspectives. Edited by V.S. Kennedy. Academic press, New York, London, Syndey, Toronto, and San Francisco. pp. 485-495.

Otto, R.G. 1971. Effects of salinity on the survival and growth of presmolt coho salmon (*Oncorhynchus kisutch*). J. Fish. Res. Board Can. 28: 343-349.

Otto, R.G. and J.E. McInerney. 1970. Development of salinity preference in pre-smolt coho salmon, *Oncorhynchus kisutch*. J. Fish. Res. Board Can. 27: 293-300.

Ready, R.C., E.L. Mills, and J.L. Confer. 1985. A new estimator of, and factors influencing, the sampling variance of the linear index of food selection. Trans. Am. Fish. Soc. 114: 258-266.

Stockner, J.G. and K.R.S. Shortreed. 1976. Autotrophic production in Carnation Creek, a coastal rainforest stream on Vancouver Island, British Columbia. J. Fish. Res. Board Can. 33: 1553-1563.

Strauss, R.E. 1976. Reliability estimates for Ivlev's electivity index, the forage ratio, and a proposed linear index of food selection. Trans. Am. Fish. Soc. 108: 344-352.

Strauss, R.E. 1982. Influence of replicated subsamples and subsample heterogeneity on the linear index of food selection. Trans. Am. Fish. Soc. 111: 517-522.

Thedinga, J.F. and K.V. Koski. 1984. A stream ecosystem in an old-growth forest in southeast Alaska. Part VI: The production of coho salmon, *Oncorhynchus kisutch* smolts and adults from Porcupine Creek. In Fish and wildlife relationships in old-growth forests. Proceedings of a symposium held 12-15 April 1982, Junea, Alaska. Edited by W.R. Meehan, T.R. Merrell Jr., and T.A. Hanley. American Institute of Fishery Research Biologists. pp 99-108.

Tschaplinski, P.J. 1982. Aspects of the population biology of estuary-reared and stream-reared juvenile coho salmon in Carnation Creek: A summary of current research. In Proceedings of the Carnation Creek workshop, A 10-year review. 24-26 February 1982. Edited by G.F. Hartman. Pacific Biological Station, Nanaimo, B.C. p. 289-307.

Tschaplinski, P.J. 1987. Comparative ecology of stream-dwelling and estuarine juvenile coho salmon (*Oncorhynchus kisutch*) in Carnation Creek, Vancouver Island, British Columbia. Ph.D. Thesis, University of Victoria, Victoria, British Columbia. xviii + 530 p.

PANEL DISCUSSION
SESSION 4: REARING HABITAT UTILIZATION

RESPONSE BY ROSS HARRIS, WONNOCK LTD.

The Effects of Logging on Stream Temperatures at Carnation Creek and Resultant Impacts on the Stock of Coho Salmon, (Blair Holtby)

Stream temperatures increased to a maximum of 3.2C in the summer and 0.7C in the winter. The warmer temperatures resulted in an earlier emergence in the spring and a resultant larger juvenile by fall. Smolt production doubled but the earlier migration to the ocean resulted in heavy mortality. This points out the necessity to study in more detail the effects of small temperature variations on life history cycles. However, since poulations of smolts actually increased after logging there is no basis for the author to state that logging should stay away from streams. The statement about detrimental effects does not involve the subject matter of his paper.

The Winter Ecology of Juvenile Coho Salmon in Carnation Creek Summary of Findings and Management Implications, (Tom Brown and Tom McMahon)

This paper focuses on the importance of overwintering habitat in the main channel and in the tributaries and swamps of a stream system.

Large complex woody debris is critical for coho fry protection in the strong autumn stream flows as it reduces water velocity. A correlation to a reduction in debris volume when clearcuts extended to the stream edge was found.

Instead of clearcutting right to the stream edge, small non-merchantable conifers and deciduous species could be left along with the mature leaners that cannot be felled into the setting.

Areas that have a sharp topographical break to the creek provide a natural point to put the falling boundary. These two methods of leaving timber should provide channel stability and a large woody debris source.

In regard to second growth stands I disagree that these stands will not produce the same quality of debris as old growth stands. Over their short rotation these stands will provide a steady debris input through the natural thinning process and the stand's susceptibility to blowdown.

With off-channel habitat the authors found this habitat to be dry in the summer and the first major autumn storm triggered movement into the off-channel areas. Water levels from the flooding determine how many coho fry make it into the swamps and tributaries. This is not true in the Kingcome watershed where coho fry inhabit the tributaries, ephermeral creeks and swamps through the spring and summer. What is important with off-channel habitat is to recognize where it is and not to impede access to it. Swamps usually have non-merchantable trees along their edge as do the major tributaries of the swamp. The trees can be left as small buffers. The ephermeral creeks cover much of the flatlands and are hard to avoid in yarding. Hand cleaning of the more major ephermeral creeks will maintain access. Ditches and culverts can be cleared of small debris by the log loader as the operator loads out the wood.

The lowland areas that flood are important to both the logging company and for fishery values. There was found to be no reduction in use by fry after logging and water levels likely increased to more favourable levels. It is important that the forest company be able to manage the site after logging with herbicides and mechanical means. This can be accomplished with ground tours with the fishery officer identifying critical areas and by getting silviculturists better informed on recognizing fish areas. The flat land areas are too valuable from a forest management standpoint to let them come back in brush after logging.

The Use of Estuaries as Rearing Habitat by Coho Salmon Fry (Peter J. Tschaplinski)

The coho fry that emigrate to the estuary in the spring have adapted to a wide range of temperatures and salinity levels. Habitat space is the important limiting factor to population levels with large woody debris creating much of that habitat. Estuaries support a highly disproportionate percentage of a watershed's population and biomass production.

The importance of estuaries increases in small watersheds especially with steep gradients where usuable habitat may end abruptly a short distance from the ocean.

Estuaries are the most valuable part of a watershed and care should be taken with activities in the estuary. Log dumps are usually off to one side or out along the inlet past the estuary to get the deep water needed. Drylands built beside estuaries should have drainage ditches directing runoff water away from the estuary and into the ocean. Unless there is no other unprotected water, log booms do not have to be stored right in the estuary. When log booms are being stored for longer periods of time, estuaries are preferred because the fresh water keeps the toredo populations and subsequent log damage reduced.

With care there is no reason why fishery production and logging-related activities in the vicinity of the estuary cannot co-exist together.

RESPONSE BY D.N. WOODGATE,
MINISTRY OF FORESTS AND LANDS

I have never been to Carnation Creek. When Tom Chamberlin asked me to act a a member of this panel, he told me that I was to do a critique of all the papers in the session from the point of view of the way that operations take place in the real world. Well, let me start by saying that the Carnation Creek Study area might be even closer to the real world than much of my own operational area, because at least here there is irrefutable scientific proof that there are fish in the creek! These days, as logging progresses further away from the mainstem (and the fish) the fishery agencies seem to be just as concerned with the effects of logging on small tributary creeks for reasons preventing debris or gravel movement from affecting downstream habitat, even when downstream may be far below and some distance away from the setting. Whereas, the forest industry, its continuing quest for cheaper logs, is sometimes reluctant to acknowledge that water does, without exception, flow downhill. And the Forest Service, who, through the referral process, takes its advice from the fishery experts but tries to keep loggers logging is often forced to mediate between the two rather than practise the integrated resource management to which we are all so dedicated.

Now I in no way intend that statement as a cheap shot but I do want to emphasize the importance of continuing the study as when logging extends to the smaller tributaries in the back end of the watershed and more accurately reflects logging in many areas on the coast.

Anyway, no one disputes the existence of coho and chum salmon and trout in Carnation Creek and this workshop is providing some essential insight into the management of the two valuable natural resources. As a resource manager, I have been listening to the three presentations and trying to pick out items which might enable me to do my job more effectively.

Tom Brown and Tom McMahon's findings on the winter ecology of coho salmon present some management implications but then qualify this by saying that management to enhance one species and life stage may adversly affect another. Having heard that winter habitat is the limiting factor for coho, I was left unclear as to just what is the off-channel contribution as habitat to overall production from the system and therefore how important it is from a protection point of view and what might be the implication of no protection. Conversely how might the off-channel be utilized in the event of deteriorations of main channel habitat. The off-channel winter habit, as described, seems to be even more sensitive to disturbance than the main-channel in terms of access, water quality, water level and physical attributes. The key seems to be in identification and recognition at the planning stage followed by proper layout and a suitable management strategy. This represents quite a challenge where we encounter not one riparian zone, but several in a west coast situation where the creek may have formed a number of channels with merchantable timber growing on the "island" between. However, if the habitat is important, this must be the price to be paid.

Blair Holtby's paper is straightforward and easy to understand. He has looked at one specific effect of the removal of vegetation on the creek environment, namely temperature, and makes an interesting observation that an increase in summer water temperature actually puts it into the preferred temperature range of the coho. But do we infer that greater or total removal of cover in the study area would have raised the temperature even higher to the point where summer stock may be stressed?

Conversly, if the creek was cooler than expected in its unlogged state, what observations have been made about the preferred temperature range for coho during the winter and spring? Is a smaller increase tolerable? The question has been raised as to how the beneficial effects of larger, stronger smolts being produced can be capatilized upon without the increased mortality due to earlier out-migration. Perhaps partial removal of streamside cover - less than has has taken place in Carnation Creek - leading to less of an overall temperature increase - might be beneficial if the accompanying increase in spring temperature is not so great as to speed up out-migration significantly.

Peter Tschaplinskis' paper deals with the use of estuaries as rearing habitat by coho and suggests that the estuary, in providing additional habitat, in this case, can provide a significant increase in population. I would therefore have liked a somewhat more detailed description of what to look for in desirable estuarine zonal characteristics in order to be able to identify such areas in other coastal locations and to evaluate their potential.

The management implications seem relatively straight forward. If the stream has a fish population which must be protected, then the estuary must be protected also and those activities associated with maintaining habitat in the creek channel can only have beneficial downstream effects on the estuary. Generally speaking, and log storage notwithstanding, the estuary is probably better protected habitat from disturbance due to unnatural causes, i.e., the removal of stable historical debris, and has a better chance of surviving as useable rearing habitat. Much of the other information in Mr. Tschaplinski's paper is not really relevant from an operational forestry point of view.

So as a layman forester having been addressed by a number of fisheries experts, what have I learned? Well, I already knew that where fish habitat is concerned, the best treatment is no disturbance to the riparian cover. In practical terms this means no felling or yarding across the stream channel, no disturbance of large stable debris and as little as possible disturbance to the tree cover, deciduous and coniferous, growing immediately beside the stream. Everything I have heard reinforces that. However, this is all predicated on the fact that the stream has been recognized from an Integrated Resource Management point of view to warrant protection and the increased cost of logging and/or foregone merchantable timber values.

I believe this is a key element behind all the deliberations at the workshop this week. Carnation Creek has been recognized as a fish producing stream and, therefore, adjacent forest management must be practised accordingly. Recognition and agreement of what are fish creeks and what are not is fundamental to our subsequent management strategies.

RESPONSE BY D.C. MORRISON, MINISTRY OF ENVIRONMENT AND PARKS

The results of these studies and the papers presented today stress the requirement for stable stream conditions including channel morphology, large organic debris (or "LOD"), and temperature. The challenge to resource managers is to determine how this can be achieved while at the same time allowing resource development and/or extraction--be it logging, mining, or whatever.

I feel the results of these studies support and justify the approach we are taking in reviewing and commenting on logging plans and silvicultural plans.

This is reflected in our management for water quality and channel stability thoughout the system and in the new Fish/Forestry Guidelines where we stress channel and debris stability and the protection of what we call fisheries sensitive zones, such as the off-channel rearing sites.

I feel that to manage a system to maintain acceptable water quality, habitat stability, and diversity requires careful management of the entire system, not just the important on-site fish spawning and rearing areas. The impacts of poor planning, poor logging practices, or poor road construction or maintenance can translocate down through the system and have diverse ramifications on habitat conditions and the fish populations supported.

The work that Peter has undertaken is significant in that it further justifies our work in estuarine habitat protection. In addition, enough particulars of estuarine habitat preferences are provided that we can use the results in creating estuarine habitat as part of our ongoing estuary enhancement projects.

However, first, I would like to know why, of the small numbers of fry marked on the Carnation estuary, only "jacks" have been observed to return, whereas in Alaska on Porcupine Creek up to 50% of the adults returning to spawn were estuary-reared fry. What factors or combination of conditions causes this difference in production of usuable adults?

I would like to mention two vegetation management factors discussed in the papers. One relates to riparian vegetation management, and the second relates to logging treatments adjacent to streamsides.

First, we recognize the problem of alder inseeding on high-site floodplain lands, but we also recognize the value of alder in stabilizing streambanks and providing detritus and insects to the system. As a compromise, for quite a few years on Vancouver Island, we have not been requesting that seed alder trees be left along the banks of small low gradient tributaries or swamps. However, we have asked that the shrubs and herbs be protected during silviculture projects to fulfill the function of alder. As Brown and McMann point out, this lesser streambank and instream vegetation has been documented as being important for fry rearing in the studies at Carnation Creek.

Second, I wish that maintenance of stream temperature and stable instream debris and the provision of future sources of large organic debris was as easy as staying away from the streambanks during logging. However, the real world is not that simple. When I started working with Fish and Wildlife about thirteen years ago the management concept at that time was to leave unlogged a one-chain or twenty-metre strip adjacent to streams. In some cases this worked well in meeting the concerns mentioned; however, in others it created problems if blowdown was severe. Blowdown is not always a problem for channel or bank stability; but I would like to know the characteristics of areas where it will be a problem if blowdown does occur. In response to problems associated with blowdown we permitted, even encouraged, logging to the streambank using directional falling equipment. In recent years, however, we have modified that approach. In some situations we are requesting some form of leave strip; in sensitive or blowdown prone areas we are still requesting directional falling, but now we are asking that "danger" trees and those with too heavy a lean to handle safely be left standing in order to provide a future source of LOD.

Given this situation regarding streamside leave strips, is the change in stream temperature resulting from logging avoidable or not? I agree with Blair that increases in summer stream temperature may not be so important to fry production and survival as temperature changes during other seasons. But, summer temperature changes may be critical for survival of summer run coho and steelhead adults holding in the streams over the summer months. Hence, I would like to see this confirmed; and if it is true, what habitat management steps may be taken to prevent this type of temperature alteration impact?

QUESTIONS
SESSION 4: REARING HABITAT UTILIZATION

Moderator: T. Northcote

JIM FRASER: I am with the Department of Fisheries and I'd like to address the whole panel but maybe in specific Dr. Holtby. Your work showed increased late winter and early fry emergence and increased water temperature at that time. My question is did you look at what effects this has on the total salmonid biomass composition, i.e., the sea run cutthroat and steelhead. populations?

DR. HOLTBY: No. I just might add it's something, that should be looked at considering predation and competition.

I should qualify the "no" a bit. There's generally speaking no interaction that we've been able to detect between coho and the other salmonids in the system but my comments on the effects of temperature should be restricted entirely to coho; I don't know what effects changes in the temperature regime had in the other salmonid species. There's some evidence, and Gordon Hartman will talk about that, hopefully, a little later this afternoon, that the same spring temperature changes affected trout populations in exactly the same way.

I don't know if there was an absence of an effect during the summer but certainly the general observation that lengthening of the growing season is an important factor probably applies to all species but I can only say it definitely to coho.

MR. FRASER: Typically in our area the trout fry would be emerging later and so if you have an acceleration of earlier movement of larger coho fry coming out, competition or predation would be affected in the late spring/summer. That's really it.

BILL POLLARD: I'm Bill Pollard and I have a question for Blair.

You showed roughly a 30 - 40 per cent increase in survival of the fish in the stream as a result of temperature then a 15 per cent decline of survival at sea and I have two questions: One, I think it might be useful for some of us from industry if you'd explain a little bit more about that relationship because I got the feeling at the end that the overall impact was. either neutral or negative. Secondly, do you have any more information for the causes of the reduction in survival at sea; do you know, what's causing the mortalities at sea?

DR. HOLTBY: First of all the increase in smolt numbers was about 100 per cent, they doubled. Survival fell by 50 percent but there were changes that were going on that I didn't have time to touch on; one is a change in the age composition, which shifted from a mix of two age classes before logging to one that was comprised of essentially only one age class after logging, and the younger age class has a slightly lower survival than the older age class entering the ocean so there's an additional fall in overall population survival there. And in fact when I say it's near neutral,. that's a problem I have. There was in fact an 18 percent increase in total population size that could be attributed to the increases in temperature. That's only near neutral in the context of the hundred percent increase in smolt production.

MR. POLLARD: Okay.

DR. HOLTBY: As far as the reasons why migration timing is important, I really don't know, it's something that has been observed in other places. It just seems that the timing of entering into the ocean is for some reason extremely critical and believe it or not, a seven-day difference can have a very large impact.

MR. POLLARD: I had one quick question for Tom

Brown. You showed 85 percent of the fish rear in the main channel relative to off channel. How does that compare with prelogging, the percent that rear in the main channel vs off channel relative to the changes that occurred in the main channel?

MR. BROWN: I don't know but it appears based on Peter Tschaplinski and Gordon Hartman's papers that the off channel use and survival was similar from before and after logging. Now, there's some considerations to be made there. First of all the population densities from the main stream are quite a bit different and also there's a lot of other factors going on in terms of differential size so I really can't say whether logging has had an effect or not. It appears that it really hasn't in terms of numbers.

DAVE BUSTARD: I've got a question for Tom Brown. Tom, you've identified these off-channel areas as being important areas for coho production and at the same time Eugene yesterday mentioned that you've had a substantial change in the water table in the valley bottom in Carnation Creek and I'm wondering if you've been able to identify whether there's been an increase or just what's happened to the total amount of off-channel habitat from preharvesting to post harvesting.

MR. BROWN: Firstly Eugene Hetherington's information is based, I believe, on summer water levels and not necessarily on winter water levels, and winter water levels are the most critical part of habitat not summer level. We don't really know but it appears in some of these situations there's a lot of muck substrate and this in fact may increase slightly, and it may be actually holding more water following logging activity so the actual habitat may have increased; I'm just speculating, I do not really know.

MR. BUSTARD: So there hasn't been an attempt to document this?

MR. BROWN: I was there prior to logging activities but I didn't have what might be considered a critical eye. I wasn't observing this problem. It appears that swamp systems such the one as you studied are still in place and are still producing fish on a very significant basis.

MR. BUSTARD: I notice that in some storms in fact there could be a movement in and a subsequent stranding and I'm wondering with the higher water tables whether this kind of thing might be less of a problem.

MR. BROWN: I did not study fall stranding but I recognize it could be quite a problem; that's why I say that the magnitude of the first fall storms may be very critical, and the timing of those storms may be critical. If they occur later in the summer but little earlier in the fall, possibly a month earlier, the fish may move in and may become stranded so that with respect to timing and magnitude it is quite essential that it take place possibly in October or November, in response to or in association with later winter storms which will occur and maintain that water level at a fairly high level.

BOB WINTER: Question for Tom Brown. As an alternative to do not avoid, stay away, no can cut, based on the work you've done and the expertise you've gained through that work, do you see any possibilities associated with the creation of artificially stable debris such as cabling smaller pieces, and creating back channel environments where deemed economically viable through artificial techniques such as backhoe work?

MR. BROWN: In answer to the second part of your question first in regards to potential backhoe work, in some of these off-channel habitats I know Jeff Cederholm and Vince Poulin have looked at blasting holes in a lot of these areas, and I have some major concerns about that. First, we do not really understand the mechanism of outmigration in spring. It may be that those fish have to undergo a period of stranding before they can move. They are within poor water conditions and higher temperatures and that may force them off. Also there's a potential that they get into these systems and in fact we don't really help because it's the amount of habitat that's available that's limiting; it's not due to deeper holes. We don't quite understand that. Another major concern is that we may blast these muck areas, create a nice, deep hole, and in fact lose our water. It may go down into the gravel in that substrate below, so there are a number of real concerns in terms of blasting and I think the stuff that Cederholm and Poulin are doing is quite important, and I think you should recognize some of these constraints that may happen in terms of blasting pools. I've forgotten what the first part of your question is.

MR. WINTER: I'm sorry, the situation whereby there may not be any large, stable organic debris but smaller pieces could be cabled together into a stable condition as a substitute for them.

MR. BROWN: I don't know. I'm wondering whether the economics of maintaining an old growth riparian strip may actually be a little less than running around trying to cable material together afterwards, and I noticed when Ross Harris made his comments, he talked about second growth management where there may be maintenance of that large debris and I'd like to ask the foresters here if after you've cleared a stream down the edge, you've paid for them, you've tended them, you've included them as part of your planning for the next cut, are you going to come along in 50 years and tell fisheries it's okay that those trees fall back in the stream for your habitat?

So I don't believe the aspects of riparian management in second growth are all that clear. We have to maintain some kind of an old growth stand and I don't know that cabling logs together, small pieces, will actually be amenable, that they will be stable for long. It's experimental and could possibly be looked at.

BOB WILLINGTON: I shouldn't actually comment on blasting and I came up here really for a question for Blair Holtby, which goes back to Bill Pollard's again. I think that one of the conclusions that you have has tremendous implications to a lot of thoughts on management and forest practices in a lot of the watershed areas and it goes back to the impact of a seven-day earlier migration into marine waters as having a fairly significant effect on survival of smolts. I understand that the date that you used to project that was developed by Koski and others at Porcupine Creek.

DR. HOLTBY: No, no, the data that I used was developed at Rosewall.

DR. WILLINGTON: I'm not familiar with that. Where is that located?

DR. HOLTBY: East coast of Vancouver Island.

DR. WILLINGTON: That actually answers the question because I thought it was Porcupine Creek and I wanted to ask if it was comparable to Barkley Sound.

DR. HOLTBY: It is comparable to Barkley Sound and the numbers that I understand have come out of Porcupine Creek from the study that I've read published by Thedinga and Koski, which I believe is Porcupine Creek, suggests that there's even more of an effect than I'm claiming, that there's a 50 per cent decline in survival with a one- to two-week earlier seaward migration. They did not look at population migration times being shifted, they divided one smolt year class into three different groups depending on when they migrated. They found that the earlier and later migrants had very much decreased or lower survivals than the majority of smolts migrating around the median time.

DR. WILLINGTON: Is there any idea on the mortality mechanism, is it predation on the fish or is it lack of food?

DR. HOLTBY: I don't know but speculate that mortality differences of that magnitude can only be accounted for by predation.

MARK SCHULER: Question for Tom Brown. On the side channel ponds that are dry in the summertime or ephemeral streams that are dry and only flow during these fall and winter storms, where's the food coming from and what is the food? Is it different than what's in the main stream?

MR. BROWN: Yes. As I pointed out, there's tremendous growth within these sites. The food appeared to be, in these situations organisms which are much different than they are within the main channel. In the main channel they tend to be benthic and I suspect most of the fish are relying on drift in the winter, just a slight bit of growth Within the off-channel habitat, many of the invertebrates are found actually on the vegetation itself and many of them are detritivores which are eating the bottom material, the leaf material. In these sites we get large entrapments of possibly alder leaves and we get large limnephylid trichopterans, which will go in and shred this stuff up; we get tremendous growth of parameletus, which is the mayfly, particularly in streams, and these appear to be extremely available to the fish. And I just speculate that there might even be some relationship between the fluctuating water levels of the channel and food consumption. The water levels will move up and down and you may actually create a nice soup of invertebrates for those fish.

SESSION 5:
FISH POPULATION RESPONSE

Moderator: G. Taylor
Ministry of Environment and Parks

A SUMMARY OF THE POPULATION RESPONSES OF CHUM SALMON TO LOGGING IN CARNATION CREEK, BRITISH COLUMBIA BETWEEN 1970 AND 1986.

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This summary consists of four parts each with the following objectives: 1) Identify and describe some characteristics of the chum salmon stock in Carnation Creek and compare them with those of other stocks. 2) Summarize the impacts of logging on the major physical processes which influence chum populations during their time in freshwater. 3) By use of a computer model, isolate logging influences from those that occur during ocean residency. 4) Discuss logging influences on the adult returns to a fishing industry.

Most studies have examined only single processes or effects over a short term. An extensive data base extending over 16 years are only now permitting us to describe logging impacts on the stock. Data from 13 complete life cycles or 3.25 generations are probably the minimum needed to determine logging influences, because patterns are only now emerging from the natural variability.

CHUM SALMON STOCK CHARACTERISTICS

Adult chum salmon enter Carnation Creek en masse during one or two freshets between October 20 and November 5. They begin spawning almost immediately and after 48 hours, few unspawned fish can be found. Most adults spawn in the estuary below the counting fence, but 3% to 25% of them pass through the fence and spawn upstream. Die-off begins a few days later and it is completed within 2 weeks.

In other areas and larger watersheds, spawners enter streams between October and January as discrete stocks of either early or late spawners (Beacham and Murray 1986; Koski 1975). The size of adults, and the relationship between female size and fecundity (Hartman 1981) is similar to that reported for other stocks (Table 1; Koski 1975). As in other streams, they return at 3 to 5 years of age, but 4 year old fish predominate (80% of spawners; Andersen 1983). Female size is also related to egg size ($r=0.65$; $N=30$; $p<0.001$) as reported elsewhere (Koski 1975), but at Carnation Creek egg sizes appear to be much larger than those reported from other stocks (Table 1). Since egg size is directly related to resulting fry size (Beacham, Withler and Morley 1985; Beacham and Murray 1985, 1986) and, since fry size appears to be a significant determinant of subsequent growth and survival (Bams 1969; Fowler 1972; Hargreaves and LeBrasseur 1986), this has major survival implications for the stock. Chum salmon in Carnation Creek can be described as early spawners that produce very large eggs and that have low energy reserves.

Table 1. Stock characteristics of some chum salmon populations.

Location		Relative size of females	Timing of Run mean (F.L.)	Mean Egg Wt. mg.	Reference
Fraser River	Jones Cr.			290.4 mg	Beacham and Murray 1986
	Alouette R.			305.6 mg	
	Vedder R.		early run	304.9 mg	
			middle run	288.8 mg	
			late run	281.9 mg	
	Chehalis R.		early run	297.5 mg	
			late run	263.2 mg	
Qualicum			early		Beacham Withler, and Morley 1985
		Large	87.4 cm	326 mg	
		Medium	82.7	323 mg	
Nitnat River			early		Beacham and Murray 1985
		Large	80.6	316.6 mg	
		Medium	71.7 cm	310.2 mg	
		Small	67.0 cm	257.0 mg	
Hoodsport and Big Beef Cr. Puget Sound			early		Koski 1975
		Large	72 cm	221 mg	
		Medium	68 cm		
		Small	62 cm		
Carnation Creek			early		
		Large	73 cm	355 mg	
		Medium	70 cm	340 mg	
		Small	64 cm	312 mg	

Eggs are deposited in the streambed where the offspring develop until spring. The eggs hatch in January, but the alevins do not emerge from the gravel until at least March. Gravel in which the eggs are incubating must be highly permeability to stream water and contain large pore spaces between particles (Bams 1969; Hartman et al. 1987). Permeability effects delivery and removal rates of oxygen, carbon-dioxide and metabilites which influence survival (Wickett 1958). Small pore size can control intragravel movement of alevins and create a barrier to emergence. Excessive quantities of finer particles (<10 mm in diameter) in streambeds reduces the values of these two properties (Koski 1975; Scrivener and Brownlee 1982; Wickett 1958). Data from some studies also indicate that mortality among larger alevins increases with fines in the streambed (Koski 1975; Scrivener and Brownlee in press; Tagart 1984).

Total time to emergence of chum salmon is directly related to egg size and to water temperature. Early spawning stocks have larger eggs and their alevins remain in the gravel longer (Beacham and Murray 1986; Koski 1975). Therefore emergence and emigration of fry in the spring tends to be synchronous for both early and late spawning stocks in an area (Beacham and Murray 1986; Hunter 1959; Koski 1975). This has major survival implications when predation is the greatest source of mortality during emigration and during early marine life (Hargreaves and LeBrasseur 1985, 1986; Healey 1982; Hunter 1959; Parker 1971). A predator's capacity for consumption is overwhelmed by the numerous prey (Parker 1971). Since the rate of development is directly related to temperature of the gravel environment (Beacham and Murray 1985, 1986; Koski 1975), temperature changes acting on a single population can affect the synchrony in timing of emigration among stocks in an area. The stock that is out of synchrony may be more heavily preyed upon. During prelogging years most chum fry at Carnation Creek emerged from the gravel and went directly to sea during April and May (Fig. 1 and 2), as shown by other populations (Healey 1982; Hunter 1959; Parker 1968, 1971).

Among chum and pink salmon fry, mortality is greatest during their first 40 days. Mortalities of 5.7% to 31.1% are reported for emigrating fry (Hunter 1959) and losses of 55% to 75% are reported during early marine life (Parker 1968, 1971). Most of these fry are eaten by piscivorous fishes such as coho, sculpins, or trout smolts. Predation rates tend to be selective by species and of smaller size fry (Hargreaves and LeBrasseur 1985, 1986). They decline as the fry become too large to be consumed. Therefore the larger fry are when they enter the ocean and the faster they can grow, the smaller this early predation is likely to be. Often fry lengths, increase to 65 mm in 40 day (Parker 1971; Hargreaves and LeBrasseur 1985, 1986). At this size, they are too large to be consumed by predators such as coho (Hargreaves and LeBrasseur 1985). Any processes that influence size of emigrating fry, timing of emigration, or early growth rates in the ocean will likely have impacts on the stock.

LOGGING IMPACTS AT CARNATION CREEK

Changes in water temperatures and in spawning gravels have effected chum populations in Carnation Creek. The temperature of the stream has increased during winter, spring, and summer as a result of logging (Holtby and Newcombe 1982; Hartman et al. 1984). Stream temperature is also directly related to the timing of emergence of chum fry (Fig. 3). Consequently, chum fry have emerged and emigrated earlier in both the estuary and the stream, since logging was begun (Fig. 1 and 2). During 1981, 1983 and 1984 emigration occurred 6 weeks earlier than during some prelogging years.

The quality of spawning gravel began declining 2 years after logging was begun. Since 1976, pea gravel (2.4 - 9.6 mm in diameter) and sand (0.3 - 2.4 mm) have increased 4.6% and 5.8%, respectively, in total composition of the streambed (Hartman et al. 1987; Scrivener and Brownlee 1982, in press). These changes are directly related to a reduction in egg to fry survival (Fig. 4) which has occurred since 1978 (Fig. 5). Gravel quality was also directly related to the size of fry that emerged upstream of the fish counting fence (Fig. 6; Scrivener and Brownlee, in press). Despite this relationship, the size of emigrating fry did not decline until 1984 (Fig. 7). This probably occurred because from 1977 to 1983, the fry were produced by larger females (Table 2) which produced larger eggs as discussed earlier. After 1983, smaller fry were emigrating because they were produced by smaller females with smaller eggs (Table 2), and because declining gravel quality reduced the emergence success of large fry.

Recruitment of adult chum salmon declined 21.7% after the 1976 brood year (Table 2), but this decline was not statistically significant (Mann Whitney U-test, $p=0.14$). It became statistically significant after the 1977 brood year (Mann Whitney, $U=9$, $p=0.04$). The increasing water temperatures affected the 1977 brood year, but changes in gravel quality did not begin effecting egg to fry survival until the 1978 brood year (spring 1979, Fig. 5).

STOCK RECRUITMENT MODEL

Five independent variables were used to develop a multiple regression model of Carnation Creek recruitment. Three of them, annual egg to fry survival (Fig. 5), median julian date of chum fry emigration (Fig. 3), and annual mean fry size (Fig. 7) were affected by logging each brood year since 1976 or 1977. The fourth, number of spawners each brood year, would be influenced by logging during their brood years. The fifth variable, surface salinity, was used as an indicator of ocean productivity. Salinities tend to be high when extensive mixing and upwelling of nutrient rich water occurs. Lower salinities occur when productivity tends to be lower or when southern water intrusions prevail during el Nino events. Mean monthly salinity was obtained from 50 years of daily surface salinities (1934-1984) that had been collected from Amphitrite Point (Dodimead 1984). A monthly anomaly from the mean was calculated by subtracting the 50 year mean from the mean of each month. Average anomaly from February to June each year was used as an indicator of marine conditions during the first months after fry emigration to the ocean.

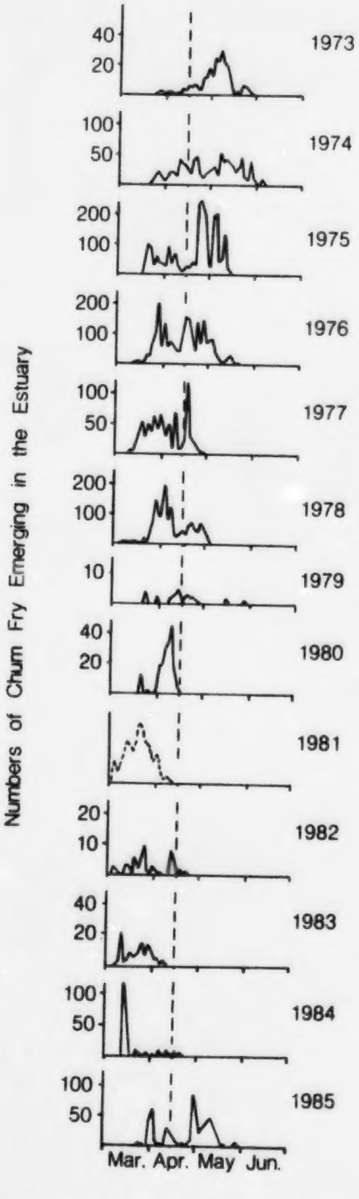

Figure 1. Numbers of chum salmon fry emerging at 2-day intervals (odd plus even days) in emergence traps in Carnation Creek estuary. April 15 is emphasized with a broken line through all years.

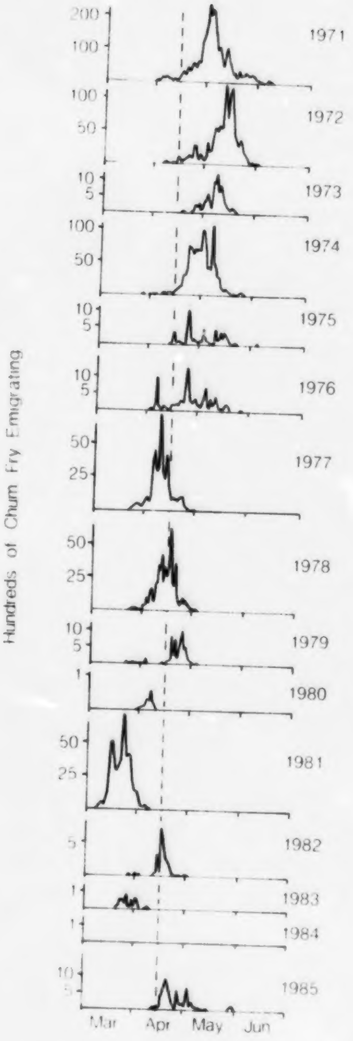

Figure 2. Numbers of chum salmon fry emigrating at 2-day intervals (odd plus even days) at the counting fence at Carnation Creek. April 15 is emphasized with a broken line through all years. No fish were caught during 1984.

Table 2. Observed and predicted values for chum salmon at Carnation Creek. The multiple regression model used number of spawners, egg-to-fry survival, Julian date of 50% fry emigration, size of fry, and mean salinity anomaly of the ocean surface during the spring for predicting recruitment. A brood year begins in autumn when eggs are deposited, while recruitment consists of adult returns 3, 4 and 5 years later.

Observed Values					Recruitment Predicted by the Model						
Brood Year	Total no. Spawners that year	Mean fork length of ♀ spawners cm.	actual recruitment (3+4+5 yr olds)		with 5 measured variables	13 yr means of salinity and no. spawners		Mean salinity and no. spawners prelogging		Mean salinity and no. spawners postlogging	
1970	2000	68.2	2920		2217	2326		2267			
1971	1000	68.3	1314		1300	2307		2349			
1972	1700	69.1	1451		1939	1675		1615			
1973	4168	70.7	1734		1865	2127		2067			
1974	3060	72.0	3096		2584	1780		1619			
1975	1200	71.9	765		1370	1691		1631			
1976	1500	72.0	2592	$\bar{x}$=1982	2329	2118	$\bar{x}$=2003	2058	$\bar{x}$=1944		
1977	1700	72.0	2390		2664	2309				2216	
1978	3300	72.2	1719		1928	880		Max-Min x 100%		796	
1979	450	72.0	1157		985	946				853	
1980	3000	69.0	924		1025	1052				958	
1981	2300	72.2	2462		2663	2965		$\bar{x}$ = 38%		2871	
1982	1600	69.8	658	$\bar{x}$=1552	314	918	$\bar{x}$=1522			685	$\bar{x}$=1395
1983	1200	69.4	-		0						
1984	950	69.1	-	Net change	88	Net change					
1985	2700	68.1	-	= -21.7%	0	= -24.0%				Max-Min x 100%	
1986	275	67.7	-							$\bar{x}$	
											=157%

All five variables were directly related to actual recruitment, but with just 13 years of data, only two of them had a greater than 90% probability of being real relationships. A multiple regression model using all five variables was significant ($F=5.16$, $p<0.05$) and explained 79% of the variability in recruitment ($R=0.89$; $R^2=0.79$). This model was used to separate logging impacts from natural variability (Table 2).

Model Predictions for Carnation Creek Chum Salmon.

Logging impacts were assessed by calculating recruitment with constant number of spawners and salinity anomaly, but with observed values for the other variables. When the 13 year mean number of spawners and salinity anomaly were used in the model, predicted recruitment declined 24.0% after logging was begun (Table 2). Since this was similar to the observed recruitment change, no unidirectional shift in both salinity anomaly and number of spawners has occurred between 1970 and 1983. Most of the observed change was attributable to logging impacts. When the mean prelogging salinity anomaly and spawner number were used, the range of prelogging recruitment was 38% of the mean (Table 2). Natural prelogging variability was nearly twice the net change attributed to logging. When the postlogging means were used, the range of postlogging recruitment was 157% of the mean (Table 2). Postlogging variability was nearly four times that of prelogging brood years. Clearly, the variability can be expected to increase. These results indicate why so many years of data are required to assess logging impacts.

Manipulation of the salinity anomaly and number of spawners with prelogging data indicated that the stock could usually be maintained with 1000 spawners. An exception occurred during years with an extremely low salinity anomaly (2 of 7 prelogging years). Here, 1400 spawners were necessary to maintain the stock. Recruits were less than 1000 and 1400 only 1 and 2 times, respectively between 1970 and 1976 (Table 2). According to reproduction curves (Ricker 1958), chum populations could have tolerated a modest fishery (20%) during 4 of the 7 years. During postlogging years, 1000 or 1400 spawners would have produced enough recruits during 3 of 6

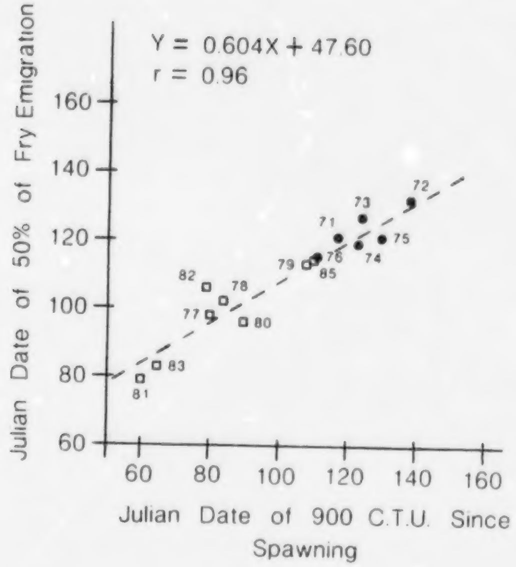

Figure 3. Relationship between winter water temperatures (degree-days) at B weir and the median date of chum fry emigration in Carnation Creek. Data from prelogging and postlogging years are indicated by dots and squares, respectively.

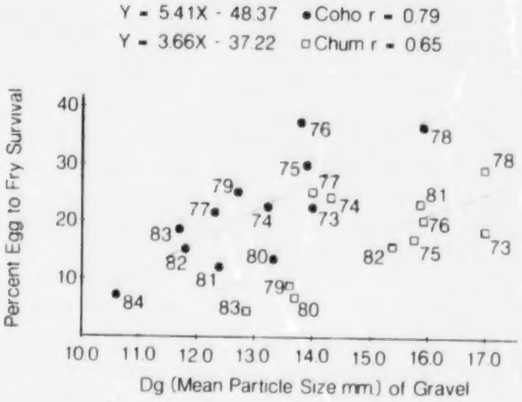

Figure 4. Relationships between annual egg-to-fry survival of coho salmon and mean particle size (Dg) in the bottom layer of freeze core samples taken from study sections II, III, IV, V, and VI; and between chum egg-to-fry survival above the counting fence and Dg in the top layer of the same gravel cores.

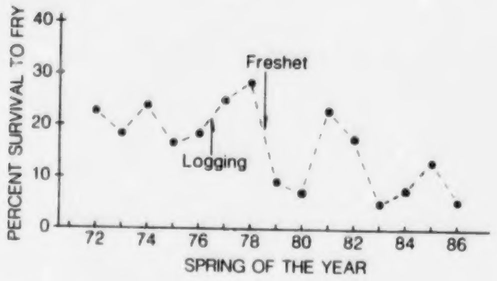

Figure 5. Annual survival from potential egg deposition to fry emergence for chum salmon above the fish counting fence at Carnation Creek. Chum salmon data from below the fence was used to estimate survival for 1984. Intense streamside logging during spring 1977 and the November 1978 freshet are also indicated.

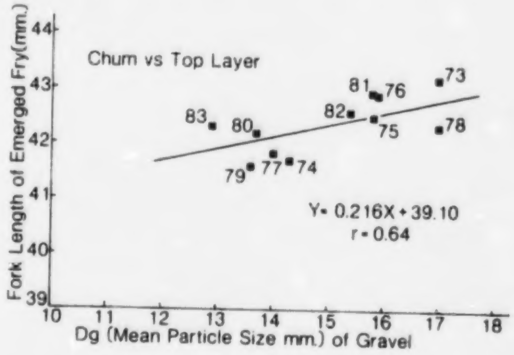

Figure 6. Relationship between mean particle size (Dg) in gravel cores from study sections II, III, IV, V, and VI and the length of recently emerged chum salmon fry from the counting fence at Carnation Creek. Fry lengths were corrected for the influence of annual variation in size of the adult females which produced the fry.

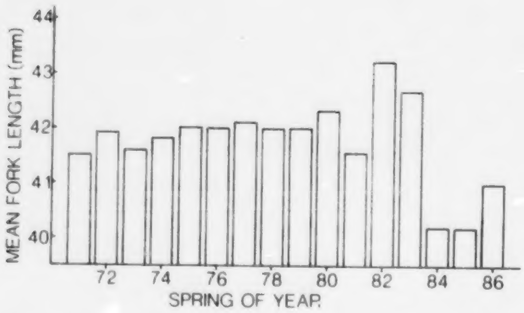

Figure 7. Mean annual fork lengths of chum salmon fry emigrating from Carnation Creek between 1971 and 1986.

years. A small fishery was possible during 2 of them. Serious recruitment problems occurred during 4 of 6 years when an extremely low salinity anomaly was used. After logging occurred, stability and resiliency of the stock to other natural and detrimental impacts have declined substantially. Harvestable surpluses were available during only half as many years.

Predicted recruitment is low for the next 3 years (brood years 1983, 1984 and 1985). Egg to fry survivals are poor and emigrating fry are small from 1984 to 1986 (Fig. 5 and 7). Numbers of spawners are below average during 1983 and 1984 (Table 2). Fry emerged early during 1984, but they emerged later during 1985 (Fig. 1). Finally, the salinity anomaly was very low during the el Nino event of 1984 and during 1986. A normal and positive anomaly was recorded during 1985. These variables predict very poor recruitment for 1983, 1984, and 1985 brood years (Table 2). These observations and predictions indicate that four consecutive poor brood years should occur (Table 2). Model predictions were also very low for these years, because it has not been calibrated with such small emigrating fry (<41.0 mm, Fig. 7).

CHUM SALMON FISHERIES

Fisheries on Barkley Sound chum stocks have had little impact on Carnation Creek chum salmon and this data base. A native food fishery occurred annually of 50 to 150 pieces. They were caught in the estuary by gillnetting from a small boat. Commercial harvesting has been greatly reduced in Barkley Sound since 1962. It has been less than 1% of escapement plus catch, 15 times, and less than 15%, 20 times during the last 24 years (Lightly et al. 1985). Commercial catch was 43%, 39%, 30% and 20% during 1980, 1973, 1978, and 1971, respectively (Lightly et al. 1985) when the largest escapements were recorded at Carnation Creek (Table 2). Most of these fish were caught in gillnet and seine fisheries on the north side of Barkley Sound. Sarita River was the only major chum salmon producer on the south side of Barkley Sound (Lightly et al. 1985). Our studies indicate why logging effects must be integrated with other natural processes influencing chum salmon populations. I conclude that the variability introduced by logging should be of more concern to resource managers than the net change observed to date.

ACKNOWLEDGEMENTS

This analysis would not have been possible without the data base contributed to by B. C. Andersen, R. M. Leahy, P. I. Neaves, T. G. Brown and many others. Dr. L. B. Holtby was consulted during data analysis and the manuscript was reviewed by G. F. Hartman and C.D. Levings.

REFERENCES

Andersen, B. C. 1983. Fish populations of Carnation Creek and other Barkley Sound streams. Can. Data Rep. Fish. Aquat. Sci. 415: 267 p.

Bams, R. A. 1969. Adaptations in sockeye salmon associated with incubation in stream gravels. p.71-87. In: T. G. Northcote [Ed.]. Symposium on salmon and trout in streams. H. R. MacMillan Lectures in Fisheries, University of British Columbia, Vancouver, British Columbia. 388 p.

Beacham, T. D., F. C. Withler, and R. B. Morley. 1985. Effect of egg size on incubation time and alevin and fry size in chum salmon (*Oncorhynchus keta*) and coho salmon (*O. kisutch*). Can. J. Zool. 63: 847-850.

Beacham, T. D. and C. B. Murray. 1985. Effect of female size, and water temperature on developmental biology of chum salmon (*Oncorhynchus keta*) from the Nitnat River, British Columbia. Can. J. Fish. Aquat. Sci. 42: 1755-1765.

Beacham, T. D. and C. B. Murray. 1986. Comparative developmental biology of chum salmon (*Oncorhynchus keta*) from the Fraser River, British Columbia. Can. J. Fish. Aquat. Sci. 43: 252-262.

Dodimead, A. J. 1984. A review of some aspects of the physical oceanography of the continental shelf and slope waters off the west coast of Vancouver Island, British Columbia. Can. Man. Rep. Fish. Aquat. Sci. 1773: 309 p.

Fowler, L. G. 1972. Growth and mortality of fingerling chinook salmon as affected by egg size. Progr. Fish-Cult. 34: 66-69.

Hargreaves, N. B. and R. J. LeBrasseur. 1985. Species selective predation on juvenile pink (*Oncorhynchus gorbuscha*) and chum salmon (*O. keta*) by coho salmon (*O. kisutch*). Can. J. Fish. Aquat. Sci. 42: 659-668.

Hargreaves, N. B. and R. J. LeBrasseur. 1986. Size selectivity of coho (*Oncorhynchus kisutch*) preying on juvenile chum salmon (*O. keta*). Can. J. Fish. Aquat. Sci. 43: 581-586.

Hartman, G. F. [Ed.] 1981. The Carnation Creek experimental watershed project report for 1979 and 1980. Pacific Biological Station, Nanaimo, British Columbia. 21 p.

Hartman, G. F., L. B. Holtby, and J. C. Scrivener. 1984. Some effects of natural and logging-related winter temperature changes on the early life history of coho salmon in Carnation Creek, p. 141-149. In: Meehan, W. R., T. R. Merrell jr., and T. A. Hanley [Eds.]. Proceedings of a symposium, Fish and wildlife relationships in old-growth forests. Am. Inst. Fish. Res. Biol. available from J. W. Reintjes. Rt. 4, Box 85, Morehead City, NC 28557.

Hartman, G. F., J. C. Scrivener, L. B. Holtby, and L. Powell. 1987. Some effects of different streamside treatments on physical conditions and fish population processes in Carnation Creek, a coastal rain-forest stream in British Columbia, p. 330-372. In: Salo, E. O. and T. W. Cundy [Eds.]. Streamside Management: Forestry and fishery interactions. College of Forest Resources, AR-10, University of Washington, Seattle, WA 98195. 471 p.

Healey, M. C. 1982. Timing and relative intensity of size-selective mortality of juvenile chum salmon (*Oncorhynchus keta*) during early sea life. Can. J. Fish. Aquat. Sci. 39: 952-957.

Holtby, B. L. and C. P. Newcombe. 1982. A preliminary analysis of logging-related temperature changes in Carnation Creek, British Columbia, p.81-99. In: Hartman, G. F. [Ed.] Proceedings of the Carnation Creek workshop, a 10-year review. Pacific Biological Station, Nanaimo, British Columbia. 404 p.

Hunter, J. G. 1959. Survival and production of pink and chum salmon in a coastal stream. J. Fish. Res. Board Can. 16: 835-886.

Koski, K V. 1975. The survival and fitness of two stocks of chum salmon (*Oncorhynchus keta*) from egg deposition to emergence in a controlled stream environment at Big Beef Creek. Doctoral thesis, University of Washington, Seattle, WA. 212 p.

Lightly, D. T., M. J. Wood, and S. R. Heizer. 1985. The status of chum salmon stocks of the west coast of Vancouver Island, 1951-1982, statistical areas 22-27. Can. Tech. Rep. Fish. Aquat. Sci. 1366: 150 p.

Parker, R. R. 1968. Marine mortality schedules of pink salmon of the Bella Coola river, central British Columbia. J. Fish. Res. Board Can. 25: 757-794.

Parker, R. R. 1971. Size selective predation among juvenile salmonid fishes in a British Columbia inlet. J. Fish. Res. Board Can. 28: 1503-1510.

Ricker, W. E. 1958. Handbook of computations for biological statistics of fish populations. Fish. Res. Board Can. Bull. 119: 300 p.

Scrivener, J. C. and M. J. Brownlee. 1982. An analysis of Carnation Creek gravel-quality data, 1973-1981, p. 154-176. In: Hartman, G. F. [Ed.] Proceedings of the Carnation Creek workshop, a 10-year review. Pacific Biological Station, Nanaimo, British Columbia. 404 p.

Scrivener, J. C. and M. J. Brownlee. In press. Effects of forest harvesting on spawning gravel quality and on incubation survival of chum (*Oncorhynchus keta*) and coho salmon (*O. kisutch*) in Carnation Creek, British Columbia. Submitted to Can. J. Fish. Aquat. Sci. 62 p.

Tagart, J. V. 1984. Coho salmon survival from egg deposition to fry emergence, p.173-181. In: Walton, J. M. and D. B. Houston [Eds.] Proceedings of the Olympic wild fish conference March 23-25, 1983. Fisheries Technology Program, Peninsula College, Port Angeles, WA. 308 p.

Wickett, W. P. 1958. Review of certain environmental factors affecting the production of pink and chum salmon. J. Fish. Res. Board Can. 15: 1103-1126.

THE EFFECTS OF LOGGING ON THE COHO SALMON OF CARNATION CREEK, BRITISH COLUMBIA

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Coho salmon (*Oncorhynchus kisutch*) is perhaps the most ubiquitous of the five species of Pacific salmon found in British Columbia. Although sizable populations of coho can be found in most lakes and larger rivers, the species is usually thought to prefer small streams. Juvenile coho commonly rear in freshwater for one or two years. This life history characteristic and their abundance in small streams potentially make this species sensitive to habitat disturbance of the sort caused by clear-cut logging.

The overall objective of the Carnation Creek study was to document the effects of clear-cut logging on the fish of a small coastal stream and most of the fisheries research effort has focused on coho salmon. The detailed and comprehensive data record at Carnation Creek now extends for 13 complete cohorts.

The objectives of this paper are: 1) to briefly describe the changes that occurred to the coho salmon after logging; 2) to present an interpretation of the mechanisms that are believed to underlie the observed changes; 3) to outline the comprehensive population dynamics model that has been developed for the coho salmon stock; and 4) to present some predictions of the future trends in coho abundance that might occur as the watershed recovers from logging.

METHODS

Two general methods were used to collect the data. First, fish movements in and out of the stream were determined at a fish-counting fence near the mouth of the stream. Adults entering the stream and fry and smolts leaving it were enumerated. Second, population sizes in the stream were estimated at least three times every year through surveys in fixed sections of the stream comprising, in total, about 10% of the total habitat available to coho. There were also more detailed studies of specific aspects of the life history. Important among these were studies of how the juveniles utilized the estuary and the side-channels, feeding studies and fish movements within the stream.

RESULTS AND DISCUSSION

Several of the important aspects of the response of coho salmon to logging can be seen in Fig. 1. The response to the first significant clear-cut logging in the winter of 1976/77 was immediate. Total smolt production from the brood year affected (1976) was almost double that of the years before logging (Fig. 1D). The change in smolt production followed a significant increase in the standing crop of juveniles found in the preceding fall. Standing crop is the product of number X weight. The average weight of individual fingerlings in the fall was strongly correlated with the abundance of fingerlings in the stream over the preceding summer. In years when densities were relatively low (brood years 80 and 81) the fingerlings grew to a relatively large size by the fall (Fig. 1C). The converse was true in brood year 1979. Some effect of logging apparently changed the relationship between fingerling abundance and size. That effect can be clearly seen in the three brood years immediately following logging (1976-1978). In those years fingerlings were about as abundant as

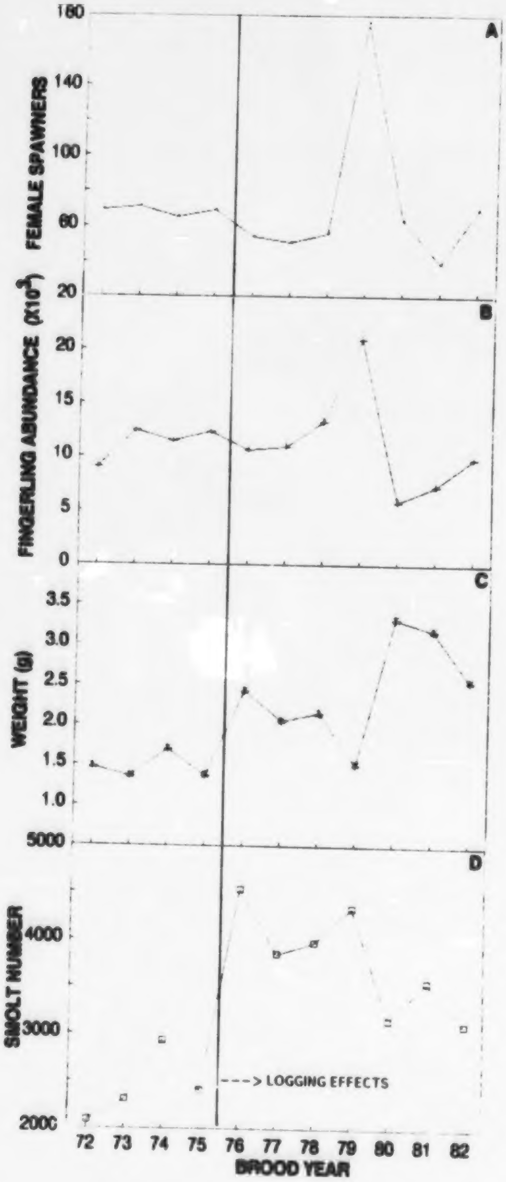

Figure 1. A) Escapement, B) fingerling abundance in the fall of their first year (brood year + 1), C) weight in the fall of their first year (brood year + 1) and D) smolt production (brood year + 2 and brood year + 3). The plots are arranged by brood year. The actual calendar years are for each panel are: A) the brood year shown, B and C) the brood year + 1 and D) brood year + 2 for yearling smolts and brood year + 3 for two-year old smolts (The smolt production is the sum of both age groups). The escapement is only females. The brood years affected by logging are shown.

they had been prior to logging but they were, on average, about 0.8 g heavier. The probable mechanism for the change in the density-size relationship is discussed later.

The increases in smolt numbers (Fig. 1D) did not result from increases in the numbers of female spawners (Fig. 1A), the numbers of fry or the numbers of fingerlings in the system at the end of their first summer (brood year + 1; Fig. 1B). In fact, smolt production is statistically independent of both escapement, (which determines the total number of eggs deposited), and juvenile abundance in the preceding summer. The increase in smolt production resulted from a change in the over-winter survivals of fingerlings (Fig. 2). The increase in over-winter survival of fingerlings appears to have been brought about by the increase in their size in the years after logging (Fig. 1C).

The considerable increases in smolt production were not translated into increased adult escapements. The greater smolt production in the years after logging resulted in only one bumper escapement (1976 brood returning in 1979; Fig. 1A). In the other years of greater smolt production that followed logging, escapements were similar to, or lower than, those observed before logging. Possible reasons for the general failure of increased smolt production to produce increased escapements are discussed later.

The increases in smolt production observed after logging were the eventual result of small increases in stream temperatures in the late winter and early spring. During the months of February and March the stream was approximately 15% warmer than it had been before logging. Increased stream temperatures during this period (and during the rest of the year as well) were probably due to the removal of the forest canopy over the lower 3 km of the stream. The stream would have warmed immediately after the removal of the canopy and so this particular effect of logging was apparent in the very first winter of logging. Increased stream temperatures either accelerated the development of incubating eggs or brought forward the emergence of fry after they hatched with the result that, in the years after logging, coho fry emerged from one to six weeks earlier than they had before logging. Earlier emergence increased the length of the growing season with the result that, for any particular level of abundance, the fingerlings were larger by the fall of the years after logging (Fig. 1C). Thus, even in the year of high fingerling abundance (brood year 1979; Fig. 1), when the average fall weight was comparable to the average observed before logging, the fry in that year were approximately 1 g heavier than they would have been at comparable densities in the years before logging.

Over-winter survival in Carnation Creek is size-dependent for 0+ coho (fingerlings entering their first winter; Fig. 3). The larger fingerlings found after logging had high over-winter survivals and smolt production nearly doubled as a result. There were also increases in the sizes of smolts (Fig. 6).

The increased over-winter survival of fingerlings and the increased size of fingerlings has led to a dramatic change in the age composition of the smolts (Fig. 4A). Prior to logging significant numbers of fingerlings remained in the stream after their first winter and smolted as 2+ smolts the following spring (Fig. 4B). After logging a much smaller proportion of fingerlings remained in the stream (Fig. 4A). Before logging the numbers of 1+ and 2+ smolts were roughly equal while after logging most smolts were of the 1+ group (Fig. 4B). The observed shift in age composition is an indication of the increase in stream productivity that resulted immediately after logging. The consequences of this change in age composition are uncertain. In theory at least, the Carnation Creek stock has become more susceptible to oscillations in numbers. The large number of yearling fish in the stream might have served to stabilize smolt production in years of recruitment failures. (Such failures might result from a poor escapement or poor egg-to-fry survival.) However, smolt production (1+ or total) is insensitive to numbers of fry over a very broad range. In other words, smolt production is strongly buffered against changes in recruitment even without the buffering capacity provided by the yearling fish.

Coho spend about 18 months in the ocean before returning to their natal streams. The causes of mortality over this period can be ascribed either to fishing or to the catch-all of "natural" sources. The coho smolts leaving Carnation Creek were never marked or tagged so it was not possible to determine in any direct way the numbers of fish caught by the sport and commercial fisheries. Consequently, no direct estimates of smolt-to-adult survivals or the proportion of the observed mortality that was due to "natural" causes could be made. In order to "link-up" smolt production with the observed returns of adult fish, it was necessary to extrapolate, from other coho stocks, relationships which explain variation in

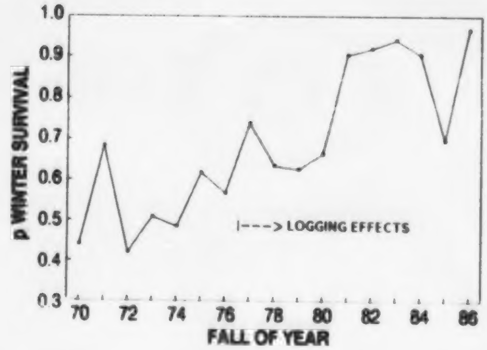

Figure 2. Proportions of fingerlings that survived the first winter in the stream. The numbers of fish in the fall going into the winter were estimated by in-stream census in late September. The numbers surviving the winter are the sum of 1+ smolts and residual yearlings present during the spring in-stream census. The years affected by logging are indicated.

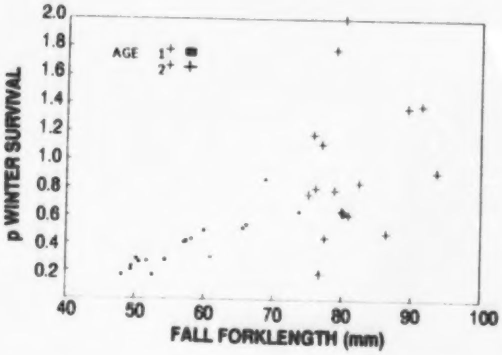

Figure 3. Proportions of fish surviving the winter as a function of fork length in the preceding fall. Both age groups are indicated.

smolt-to-adult survival.

Two of the presumably many factors which can affect the survival of smolts are smolt size and the time of migration. Generally larger smolts that migrate late in the spring survive better than smaller smolts that migrate early in the spring (Bilton et al. 1982). Logging and to a lesser extent, climatic variation, affected the size of smolts and the timing of their entry into the ocean. Small increases in spring water temperatures brought forward the seaward migration of coho smolts by from 7 to 14 days (Fig. 5). Smolts, particularly yearling smolts, were generally larger after the beginning of logging (Fig. 6). Over the ranges of smolt weight and migration time observed, variation in smolt survival is determined more by variation in migration timing than in weight. Smolt-to-adult survival is predicted to have decreased from 15% before logging to 10% in the years after logging. This predicted decline in survival was caused by earlier migration and assumes a constant ocean environment. I would like to emphasize that such a decline in smolt-to-adult survival was not directly measured, nor could it be measured, for Carnation Creek coho. The stated decline in survival was calculated from the relationships generated by the time and size-at-release experiments of Bilton et al.

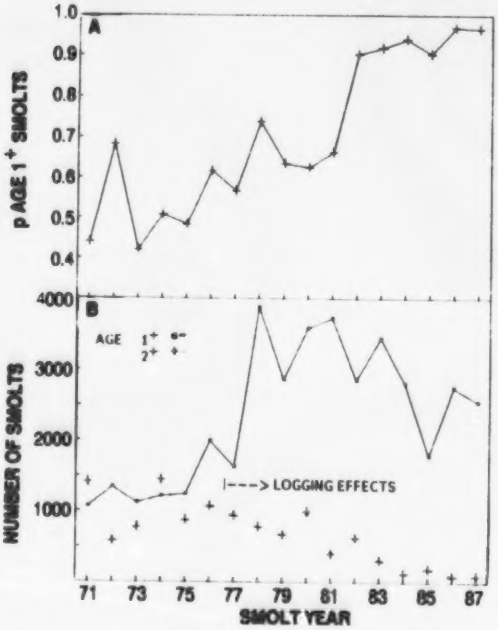

Figure 4. A) The proportion of smolts that were age 1+ by year of migration. B) The observed numbers of yearling (1+) and two-year old (2+) smolts by year of migration. Note that for any particular cohort, the two-year old smolts migrate one year after the yearlings. The change in the age composition of smolts resulted from the dramatic increase in the numbers of the younger age group (1+) rather than an abrupt decline in the numbers of older smolts.

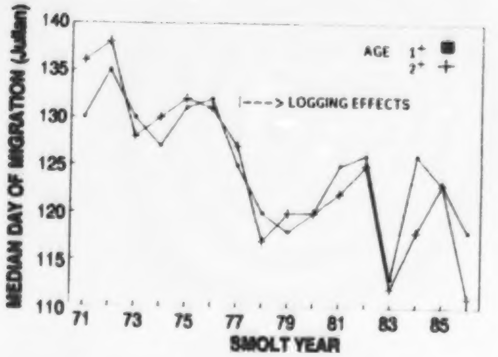

Figure 5. Median Julian day of migration of yearling and two-year coho smolts from Carnation Creek by year of migration.

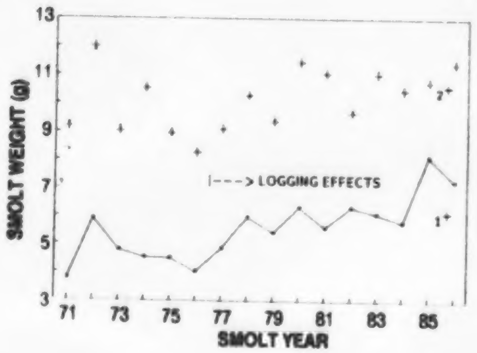

Figure 6. Mean weights of yearling and two-year old coho smolts by year of migration. The years affected by logging are indicated.

(1982) for coho released from the Rosewall hatchery. Similar declines in survival with early release have been observed at other hatcheries (pers. comm. B. Morley, Pacific Biol. Sta., Nanaimo, B.C.). The only study on the effects of migration timing for wild coho of which I am aware was done at Porcupine Creek, Alaska (Thedinga and Koski 1984). There, smolts migrating 1-2 weeks before or after the peak migration had 50% the survival of smolts migrating during the peak period. The reasons for such a strong dependence of survival on migration timing are unknown.

The increased mortality of smolts that may have resulted from earlier entry into the ocean would have partially reduced the impacts of increased smolt production on the magnitudes of subsequent adult returns but those impacts do not fully explain the discrepancies between observed smolt numbers and adult returns to the stream (compare Fig. 7A and Fig. 7D). It is probable that there were changes in "natural" mortality and/or fishing mortality over the course of the study. Fortunately it has been possible to estimate mortality due to the fishery and natural causes using data gathered from coded-wire tagged releases of coho from the nearby Robertson Creek hatchery. The application of natural and fishing mortality rates from Robertson Creek necessitate the important but untestable assumption that coho from the Robertson Creek hatchery behave similarly in the ocean to coho from Carnation Creek. The assumption that hatchery stocks can be used as indicators of wild stocks has been widely made but is only now being critically examined through field experimentation (pers. comm. C. Walters, U.B.C., Vancouver, B.C.). Although fishing mortality has been variable (Fig. 7C), there has been no systematic change that would explain the discrepancy between potential and observed returns to Carnation Creek. Furthermore the very large return from smolt year 1978 (brood years 1975 & 1976, return year 1979, Fig. 7D) cannot be explained by a decrease in the fishing mortality. However, there has been a substantial and systematic decline in smolt-to-adult survivals of the Robertson Creek coho (Fig. 7B). Similar declines in smolt survival have been observed for sockeye salmon smolts originating in Barkley Sound (pers. comm. K. Hyatt, Pacific Biol. Sta., Nanaimo, B.C.). Furthermore, the variability in smolt-adult-survival is significantly correlated with sea surface temperatures and salinities in Barkley Sound around the time of smolt migration, suggesting that the variability in smolt-to-adult survivals in some way results from variability in ocean "conditions". It is reasonable to assume that the marine survival of Carnation Creek smolts also declined.

Escapements to Carnation Creek were predicted from smolt numbers as follows: 1. the observed smolt numbers for each year (Fig. 7A) were multiplied by the survival rates calculated from the time and size- at-release relationships discussed above to give expected adult numbers before all fisheries and assuming constant ocean conditions. (Although not shown in the figure, the two age classes of smolts were kept separate throughout all of these calculations); 2. the expected adult numbers from 1. were multiplied by a standardized survival calculated from the observed smolt-to-adult survivals for the Robertson Creek hatchery coho (Fig. 7B). Those

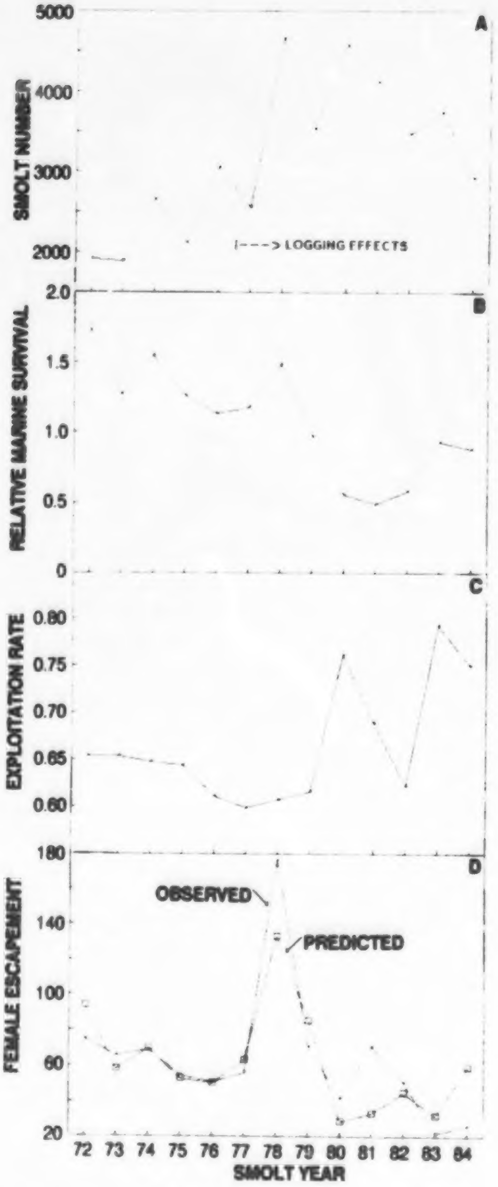

Figure 7. A) Smolt production, B) relative marine survival, C) fishery exploitation rates and D) escapements arranged by smolt year. Note that the smolt production is the sum of both age groups and that escapements are for females only. Relative marine survivals and fishery exploitation rates were calculated from coded-wire tagged releases of coho from the nearby Robertson Creek hatchery.

survivals include all fish captured in the commercial and sport fisheries. The estimate produced here is for total number of adults that were present immediately prior to the fishery; and 3. the number of adults estimated in 2. were multiplied by one minus the fishery exploitation rate observed for the Robertson Creek coho (Fig. 7C). The number produced is the expected escapement to Carnation Creek. This sequence of calculations makes reasonable predictions of observed escapements (Fig. 7D).

Since logging affected both the weight of smolts and the timing of the smolt migration, changes in the numbers of adults caused by changes in either of these smolt parameters are properly considered effects of logging. Changes in smolt-to-adult survival that were due to changing ocean conditions or to changes in fishing mortality are clearly not effects of logging. Therefore, the net effect of logging on the coho stock must be estimated using the numbers of adults predicted by step 1 above. The net effect of logging is expressed in terms of percentage change in the numbers of adult females relative to the average number presumed to have been present before logging (Table 1). On average, in the years following logging, the total number of adult female coho increased by an average of 9% over the number present prior to logging (Table 1).

Generalizations about Coho Population Ecology

In developing the explanation for the observed changes in coho abundance after logging, that were presented above, several generalizations about the population ecology of coho of Carnation Creek have become apparent.

First, smolt production in Carnation Creek is limited (or controlled) more by physical factors than by biological ones. For the Carnation Creek coho stock there are three important production bottlenecks in freshwater: egg mortality, fry mortality immediately after emergence and mortality of fingerlings over their first winter in the stream. All three processes seem to be controlled by physical processes rather than biological interactions, and, for the most part, mortality rates are density Independent. In this regard, Carnation Creek is probably typical of small streams of low productivity, in regions of cool temperatures and dynamic flow regimes. In streams

Table 1. Estimates of total adult female returns prior to the fishery, averaged over the before and after logging periods. The smolt years before logging "<LOG" were 1971-1976, those after ">LOG" were 1977-1984. The effects of logging and climate are shown as both absolute numbers of females and as percentages of the pre-logging estimated returns. Logging effects are calculated by using the estimated returns with and without logging. Climatic effects are calculated by using the estimated returns without logging for the before and after logging periods.

Smolt age	Period	Estimated returns		Effects of	
		with logging	without logging	logging	climate
1+	<LOG	99	99	-	-
	>LOG	159	130	+29/+29.3%	+31/+31.3%
2+	<LOG	84	84	-	-
	>LOG	30	43	-13/-15.5%	-41/-48.8%
total	<LOG	183	183	-	-
	>LOG	189	173	+16/ +8.7%	-10/ -5.5%

of higher productivity with, perhaps, warmer temperatures and more benign flow regimes, density-dependent, biological controls probably predominate. Carnation Creek can be thought of as representative of one end of the physical-biological control continuum envisaged by Allen (1969).

Egg mortality is determined largely by gravel quality and by peak scour events (Holtby and Healey 1986; Scrivener and Brownlee 1982). Gravel quality was adversely affected by the logging practices used in Carnation Creek and there have been significant increases in egg mortality. Over the range of spawner densities that have been observed, there is no evidence that any biological factors (e.g. numbers or size of spawners) affected egg mortality. In other streams where spawner densities are higher and flow regimes are more benign, total egg mortality is affected by spawner densities and the survival of eggs in individual redds is strongly influenced by parental size (van den Berghe and Gross 1984).

Mortality of fry soon after emergence is determined by flow conditions around the time of emergence and some, as yet poorly understood habitat limitation. Except when total fry emergence is greater than 45,000 (which has been the case in only one year), a constant proportion (.54) of emergent fry leaves the stream. Some of the fry that are displaced downstream take up residence in the estuary but there is no evidence that these fry make a disproportionate contribution to adult returns. The number of fry which took up residence in the stream was not affected by the number of fry that emerged and competition among the fry for territories within the stream does not appear to have been an important factor determining resident fry numbers, except when emergence was very large (>15,000 fry/km).

The single most important factor limiting coho production from Carnation Creek is mortality of fingerlings during their first winter in the stream. A large decrease in this mortality (Fig. 2) in the years immediately after logging was responsible for virtually all of the increases in smolt production that were observed. Over-winter mortality of juvenile coho is strongly related to the size at which the fish enter the winter. In the years immediately after logging coho fingerlings were up to 60% larger going into the winter than they had been prior to logging (Fig. 1C) and mortalities during those winters fell correspondingly (Fig. 2).

Winter mortality was also related to the physical integrity of the stream channel. The structural complexity of the stream appears to be an important requirement for high winter survivals. In fact, an increased appreciation of the importance of large organic debris (Tschaplinski and Hartman 1983), side-channel winter habitat (Bustard and Narver 1975) and off-channel sloughs in the over-winter survival of coho has been one of the important contributions of the Carnation Creek study. The importance of over-winter mortality in limiting coho production is becoming more generally recognized (eg. Heifetz et al. 1986).

The logging practices used in Carnation Creek severely damaged the stability of the stream banks in about 40% of the stream utilized by anadromous fishes (Hartman et al. 1987). The removal of large organic debris from the stream channel appears to have been particularly damaging. As a direct result of streamside disturbance there have been significant declines in the amount of summer and winter rearing habitat over at least half of the stream length. These changes have apparently resulted in harsher winter conditions in the stream and increased mortality during the winter. Winter mortality is not related to fish densities during the winter, however, suggesting that the fish are not competing between themselves for prime habitat.

Until recently there has been little evidence to suggest that summer conditions affect smolt production from Carnation Creek. Smolt output was not correlated with any measured summer condition, and in particular, there was no evidence that smolt output varied with minimum summer discharge or with available rearing area at summer low flow. Although summer stream temperatures increased considerably after logging there was no evidence that those higher temperatures adversely affected the juvenile salmon. However, in the aftermath of a major debris torrent in the upper section of the anadromous zone in the winter of 1984, extensive de-watering during the summer has now been observed and rearing populations in the upper sections have fallen. If habitat damage extends further down the stream, which appears likely, then it is highly probable that severe de-watering will affect as much as 40% of the stream. During dry summers this will almost certainly affect smolt production.

The second general principle to emerge from the study is that the initial logging impacts on the coho were effected by changes in the timing of important life-history events. Most of the initial impacts of logging can be understood by first examining the effects that logging had on the temperature regime of Carnation Creek and then by examining the effects that those temperature changes had on the timing of two events, fry emergence and smolt migration. The timing of both fry emergence and smolt migration was disrupted by small changes in stream temperature during the late winter and spring. Earlier fry emergence was largely responsible for the increases in smolt production observed immediately after logging. Earlier smolt migration was partially responsible for the failure of increased adult returns to be realized from that increased smolt production. Significantly, the effects that these temperature perturbations had on the abundance of coho were in opposite "directions" and the net effect on the stock was small.

Third, logging impacts on the coho salmon can be roughly divided into two general types: those related to stream temperatures and those related to channel integrity. Both increased stream temperatures and decreased channel integrity resulted directly from streamside logging. In many respects the natures of these general impacts are quite different (Table 2). Thermal impacts were immediate, were relatively easy to measure, for the most part are easy to understand, and had a modest and positive benefit in that smolt production and adult abundance were enhanced. Furthermore the future time course of the thermal effect can be readily anticipated: the thermal effects are expected to gradually wane as the streamside revegetates. On the other hand, physical effects have been slow to develop, develop in response to chance events such as large storms and debris torrents, are difficult to quantify (but, perhaps, are also readily understood) and are uniformly destructive to fish production. Physical effects are not only difficult to quantify but they are exceedingly difficult to anticipate quantitatively. Subjectively, it seems reasonable to expect that the physical integrity of the stream banks and channel will continue to decline for many years, but exactly how and to what extent cannot be predicted. Anticipating the effects of future change in the stream on the productive capacity of the stream is even more difficult.

Fourth, variability in the survival of smolts in their first few months in the ocean was an important source of the year-to-year variation in coho abundance. Even though adult returns to Carnation Creek were predicted to increase by an average of 9% after logging, escapements actually fell (Fig. 7D; with the exception of the return in 1979 from smolts produced in 1978). This apparent decrease in ocean survival was also observed for coho released from the nearby Robertson Creek hatchery where survival by 1983 was one-third of that observed in 1973 (Fig. 7B). The decline in smolt survival is not due to any change in the fishery exploitation rate but is correlated with the warming of sea surface temperatures off the coast of Vancouver Island.

Modeling the Effects of Logging on the Coho Salmon

The wealth of biological and physical data collected in

Table 2. A summary of the characteristics of the two basic types of logging perturbations that coho responded to in Carnation Creek.

Type	Thermal	Physical
Period of effect (years after logging)	0-?30	5-?100
Major effect	increased stream temperatures	channel instability bank erosion loss of large organic debris loss of winter and summer habitat
Biological effects	changes in timing of critical life history events	increased mortality
Net effect on coho	average 9% increase in adult	negative and increasing, but magnitude unknown
Quantification of effects	yes, easily accomplished	partially, difficult to quantify and difficult to relate physical changes to fish production
Future effects	fairly easy to anticipate stream will cool as bank revegetates	very difficult to anticipate extent and severity of future physical degradation and restabilization
Applicable elsewhere?	limited: absence of effects of higher summer temperatures only to other cool coastal streams; impacts on timing of life history events not detected in other studies	historically yes, but modern logging practices preclude damage to stream bank or channel

Carnation Creek has enabled me to develop a model of the entire life-cycle of coho salmon. The model is comprised of approximately 30 relationships between physical and biological factors (the independent variables) and the survival and growth of coho at most life stages (the dependent variables). Growth in the ocean was not modeled. The individual relationships are linked together so that the output of any one step of the model serves (where appropriate) as the input to the next. Starting with the number of females and their size in the first generation and with time series of physical variables (e.g. temperatures, flows, etc.) and independent biological variables (e.g. fishing pressures) the model predicts escapements for the duration of the time series provided. The relationships of particular importance to this discussion are detailed in Table 3.

I have used the simplest form of the model for this summary in that I follow the progeny of the original spawners for many generations. The real situation is somewhat more complex since there are two smolt age groups and a large percentage of the male smolts (25%) mature precociously. Consequently, the progeny of each brood return to spawn over three years and not one, as I have assumed. Furthermore, the adults return after 18 months in the ocean during which time the progeny of three earlier broods have spawned. The results of using a more realistic but computationally more complex model are similar to those produced by the simple model however.

The time series of physical and biological variables can be used to simulate the number of adults (or numbers at any other life stage) that were actually

Table 3. The important relationships from the coho life history model developed for Carnation Creek. "Modifiers" are the independent variables that were significantly correlated with the observed rate in the "Modeled Relationship". The "Effect on Recruitment" column shows the effect that changing the independent variable (in the direction shown to the left of the arrow) had on recruitment (the number of adults), e.g. "+ ->–" indicates that increasing the independent variable had the effect of decreasing recruitment. The final two columns indicate whether logging or climate determine the level of each independent variable. "FW spring temperature" is the stream temperature during the months February through April. "Habitat quality" is a qualitative measure of stream stability and of the amount of large organic debris present.

COHO MODEL

Modifier	Modeled Relationship	Effect on Recruitment	Affected by	
			logging	climate
gravel quality	**egg→fry survival**	+ ⇒ +	●	
peak discharge	**egg→fry survival**	+ ⇒ -	●	
FW spring temperature	**fry emergence timing**	+ ⇒ +	●	●
	smolt migration timing	+ ⇒ -	●	●
habitat "quality"	**winter survival**	+ ⇒ +	●	
ocean surface temperature	**smolt→adult survival**	+ ⇒ -		●
ocean surface salinity	**smolt→adult survival**	+ ⇒ +		●

observed at Carnation Creek, or they can be set to explore the effects of hypothesized trends in stream conditions after logging.

I used the model in three ways. First, by holding all independent variables constant I examined the relationships between adult production and spawner numbers, i.e. the stock-recruitment relationships. Stock-recruitment relationships are used extensively in the management of fisheries to estimate such stock parameters as required spawner escapements, maximum sustained yields, permissible harvest rates, and relative stock productivities. By holding all of the independent variables constant at pre- or post-logging values the effects of logging on the stock-recruitment relationship can be calculated. Second, by holding all but one of the independent variables constant, I have examined how fish numbers vary over a range of values for that one independent variable. By doing this I could estimate what the effects of specific logging effects were, independent of all other effects. For example, by holding all of the independent variables constant except gravel quality, I could estimate what impacts logging had on the stock that were operating through changes to gravel quality alone. Third, by assuming various time series for recovery after logging (principally forest regrowth and channel restabilization) I have simulated possible futures for the Carnation Creek coho stock.

Stock-Recruitment Relationships

I have calculated the stock-recruitment relationships under four sets of stream conditions: 1) average values of all physical variables before logging, 2) average values three years after logging was completed (the peak of the temperature perturbations but before any physical degradation of the stream was observed), 3) hypothetical conditions 11 years after logging (temperature effects are beginning to wane, gravel quality is seriously degraded and destabilization of the stream channel is accelerating and 4) hypothetical conditions 30 years after logging (the temperatures and the gravel quality have returned to the pre-logging state, but the stream channel remains unstable). I emphasize that scenarios 3 and 4 are possible futures only. The form of the stock-recruitment relationship predicted by the model is of the classical Ricker type (Ricker 1975) with a broad peak of production at intermediate escapements and declining production at higher escapements (Fig. 8). The stock was most productive immediately after logging and is predicted to be least productive 30 years after logging (Table 4: productivity is gauged by the R/S or recruits/spawner ratio. R/S values of 3-4 are typical of coastal coho stocks). Before logging, maximum surplus production was attained with between 50 and 60 female spawners (about 18 to 20 females per kilometer of stream or slightly below the average before logging); and 3) the exploitation rate at maximum sustainable yield varies from 61%, 30 years after logging when the stock is predicted to be least productive to 75%, 3 years after logging when the stock was most productive. Currently the average exploitation rate is approximately 65%. Under the stream conditions that might be present 30 years after logging the Carnation Creek stock would be somewhat over-exploited. However, under stream conditions like those observed before logging and thus far after logging the stock would remain healthy provided that all of the other production parameters remained near average. In fact, marine survivals independent of any logging effects have not remained constant but have declined by as much as 60% since the mid-seventies (Fig. 7B). This decline in ocean survival is partially responsible for the absence of large increases in adult returns following the increased smolt productions observed after logging. As a result the Carnation Creek stock and probably most others in the Barkley Sound area were seriously over-fished in the early eighties.

Simulations of Single Factor Effects

In the second set of simulations I varied, singly, gravel quality, peak winter discharge, stream temperatures, ocean survival (smolt survival independent of logging effects) and channel stability. Each of these variables, (for temperatures a set of 5 variables), was varied over the observed range of the past 15 years. All other independent variables in the model were held constant. The results (Fig. 9) are measures of the sensitivity of coho production to variation in each of the variables. The variables in descending order of importance were: ocean survival > stream temperature = channel stability > peak winter flows = gravel quality. The sensitivity of coho production to these variables, when production is measured by adult returns follows the reverse chronological order in which the variables affect survival.

The model can also be used to estimate the effects of logging independent of climatic factors by using the time series of stream temperatures predicted in the

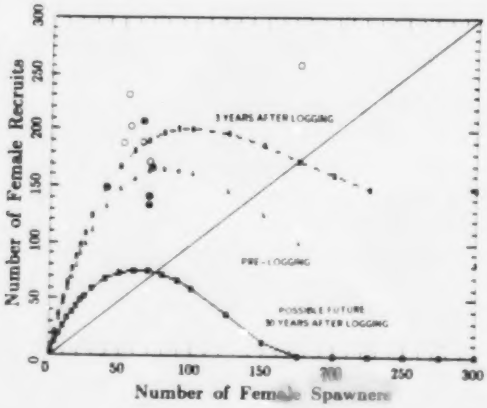

Figure 8. Stock recruitment curves for the Carnation Creek coho stock. The curves were calculated using the coho model by varying the numbers of spawners and calculating the eventual returns while holding all independent variables constant. The results of this simulation with three sets of assumptions are shown: i) all independent variables were set to average conditions observed before logging; ii) all independent variables were set to average conditions three years after logging, i.e. maximum coho productivity; and iii) all independent variables were set to hypothetical conditions 30 years after logging, i.e. minimum coho productivity. The closed circles are the actual observed values before logging and the open circles are the actual observed values after logging. Note that the stock-recruitment curves were not fitted to the observed values but are the predicted relationships generated by the coho model described in the text. The diagonal line is the replacement line.

absence of logging (described elsewhere in this volume), and by setting other physical variables to the average values observed before logging. On average, logging produced a 9% increase in adult numbers (Table1). Had logging not occurred, the model estimates that adult numbers would have declined by about 5.5% due to natural variation in stream temperatures. (Both of these estimated changes in adult numbers assume constant ocean survival of smolts and are calculated prior to all fisheries.)

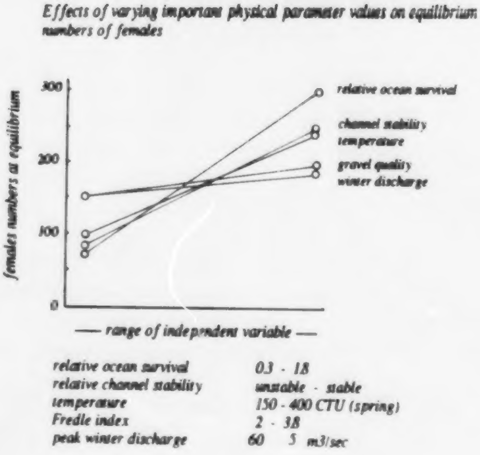

Figure 9. Model sensitivity to variation in the independent variables. The curves were calculated using the coho model by setting all independent variables to the conditions observed before logging. The five independent variables shown were then varied singly over the range shown and the number of females at equilibrium was calculated. (This number is found where the stock recruitment curve crosses the replacement line.) Note that the ranges of the independent variables have been depicted as going from severe (in terms of their effects on recruitment) on the left to benign on the right so that in some the values of the variables are reversed (e.g. peak flows).

Of particular interest in these result is the equivalence of temperature effects and effects of logging on the integrity of the stream channel (Fig. 9). Remembering my general characterizations of these two general logging impacts (Table 2) it is fairly easy to anticipate the model projections of future time series of coho abundance after logging (discussed in the next section).

Speculations on the Future

Lastly, I simulated a possible future time series of smolt and adult abundance (Fig. 10). In this simulation logging occurred in the 75th year. The model predicts nine years of heightened production immediately after logging due to the predominance of temperature effects. This short period is followed by 30 years or so of declining abundance as the temperature effects wane with revegetation and the physical effects begin to predominate. Full recovery

Table 4. Stock-recruitment parameters for the Carnation Creek coho stock under four sets of assumptions. All values were calculated at the point of maximum sustainable harvest. The actual harvest can be calculated from the exploitation rate and the spawner density. R/S or recruits per spawner is a measure of stock productivity. Productivity is highest immediately after logging when the beneficial thermal effects are greatest and there have been few deleterious physical effects. Conversely, productivity is lowest 30 years after logging when stream temperatures have returned to pre-logging levels and physical effects are greatest. This modeling assumes that ocean conditions are constant.

Time	Females/km	Adults/km	R/S	%exploitation
pre-logging averages	17.8	40.6	3.01	66.7
3 yr. post-logging	26.7	60.9	4.00	75.0
11 yr. post-logging	24.2	55.2	2.78	64.0
30 yr. post-logging	12.2	27.8	2.54	60.7

does not take place for almost 100 years after logging. This result is purely speculative of course, since the rates of channel destabilization and restabilization, gravel quality and stream temperatures are hypothetical. Nevertheless the stability of the channel was not assumed to get any worse than it already is, just 5 years after the completion of logging. The temperature effect does appear to be lessening and it is reasonable to expect that the canopy will close over the stream 15-20 years from now as the model assumed. It is probable that large organic debris will continue to disappear from the system for at least the next 50 years (Grette 1985) and recovery may be further delayed by renewed logging activity in the upper watershed.

When the simulations are run deterministically, that is to say without environmental uncertainty, the projected time series of smolt production and adult (female) abundance appear disarmingly simple and the predicted abundances, even during the worst years are not cause for concern (Fig. 10). However, when realistic levels of environmental uncertainty are added, including natural levels of variability in ocean conditions, smolt production and escapements become very erratic (Fig. 11). At various times female escapements fall below 20 fish. (Note that an escapement almost this low has already been seen after logging!). Predicted reductions to fewer than 20 female spawners of stock occurred anytime from 20 to 100 years after logging. Severe depressions in adult numbers were most frequent when logging damage to the stream channel and ocean survivals were at their worst simultaneously, and there was a succession of severe winters.

Several reviewers of this paper have been particularly critical of this particular section of the paper, and especially its apparent pessimism. Although the model is being extended far into the future in what is clearly a speculative exercise, I have carefully avoided making arbitrary decisions about the future condition of the stream. In particular, conditions in the stream channel were not assumed to get any worse than has already been observed. Furthermore, the expected time course of recovery is based on my understanding of the latest research results concerning the importance of large debris and its dynamics in logged-over streams (Bisson et al. 1987; Grette 1985) and the dynamics of canopy closure. The predictions of occasional dips in female escapements to 20 do not appear unrealistic in light of returns in recent years. To assert, as some reviewers have that recovery times will be very rapid is, in my opinion, to fly in the face of increasing evidence that historical logging practices severely disrupted the normal dynamics of large organic debris in small streams (Bisson et al. 1987). However, only time, or further research into the current status of streams logged decades ago, will help resolve the question of the future state of Carnation Creek.

CONCLUSIONS

The coho salmon in Carnation Creek responded to two different kinds of habitat perturbations produced by logging (Table 2). Thermal effects were immediate and operated through changes in the timing of critical life history events. The thermal perturbation has had a modest beneficial effect on coho production. The large effects that the thermal perturbations had on

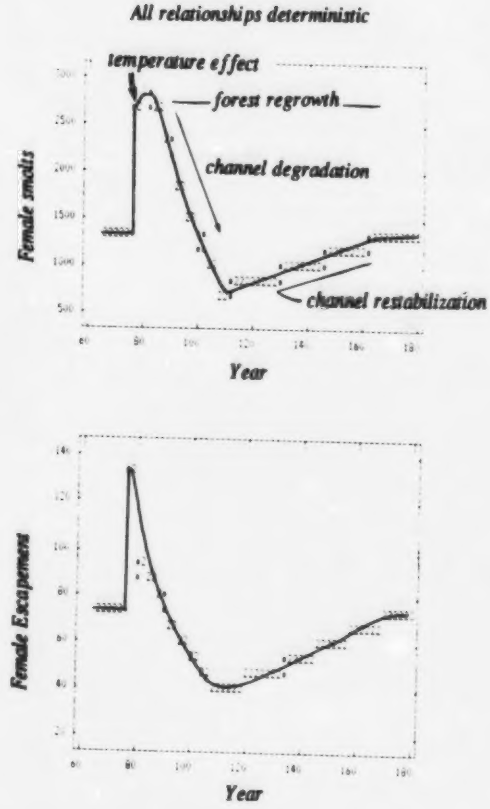

Figure 10. Hypothetical time series for the Carnation Creek coho stock in the aftermath of logging. All of the relationships are deterministic which means that there is no uncertainty in the model's predictions. The major events following logging in year 75 are shown. The model assumes that 40% clear-cutting occurred in year 75 and that there was no further stream disturbance.

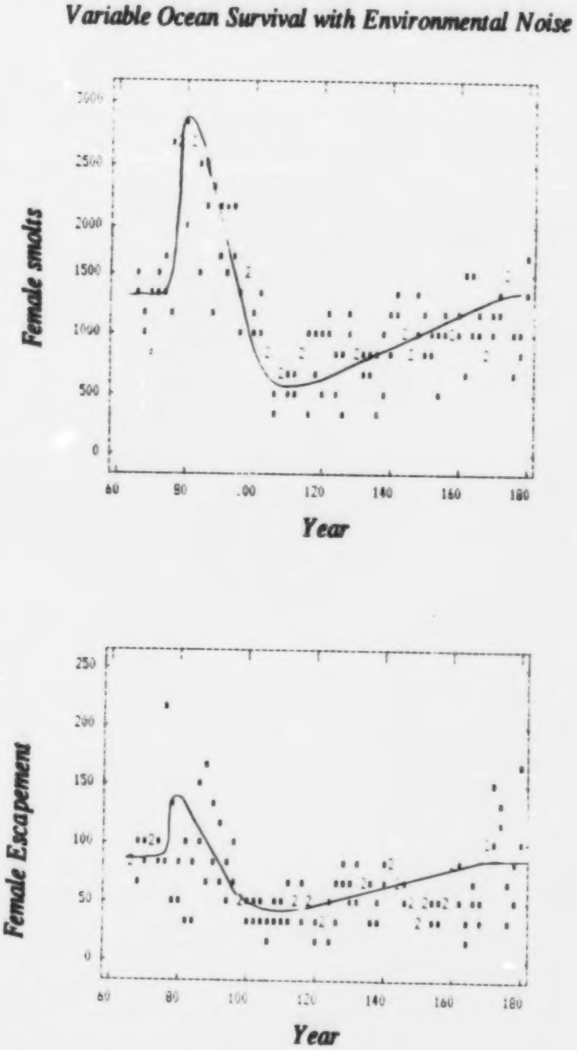

Figure 11. Hypothetical time series for the Carnation Creek coho stock in the aftermath of logging. This is the same simulation as shown in Fig. 10 except that realistic levels of environmental variation have been introduced. On several occasions predicted escapements fall below 20 females.

the coho are interesting in several respects. First, the thermal effects were indirect; in other words the temperature changes themselves did not change survival or growth rates. Instead, the temperature changes affected the timing of fry emergence and smolt migration. Second, the temperature perturbations were separated in time from their effects. In the case of early fry emergence, the effects on survival of elevated temperatures during February and March were not realized until the following winter. Third, the temperature effects came at an unexpected time of the year, late winter and early spring. Concern over the effects of logging on stream temperatures has typically focused on summer temperature elevations. In cool coastal streams such as Carnation Creek, temperature elevations during the summer probably increase temperatures into the preferred range of coho. Fourth, the temperature changes observed in early spring affected two different life stages of coho in "opposite" directions. The idea that habitat perturbations can affect different life stages simultaneously but differently is not novel, but was well demonstrated in Carnation Creek.

The coho have also been affected by physical changes to the stream caused by logging. In contrast with the thermal effects of logging, the physical effects were much slower to appear, are accelerating and have been entirely negative. Like the thermal effects, the physical effects stem largely from logging activity adjacent to and in the stream. The loss of stream habitat that has occurred affects juvenile coho throughout the time that they are in the stream. Loss of winter habitat has affected the fish sooner but de-watering of summer habitat now appears to be occurring as well. Loss of winter habitat has already significantly reduced the benefits of warmer stream temperatures on coho smolt production. However, the full extent of the effects of stream degradation will be seen only when the streamside revegetates and the temperature effects moderate. The future effects of summer habitat loss are uncertain.

The Carnation Creek study has certainly provided a wealth of information about coho salmon in a small coastal stream. Perhaps the most important information to come out of the Carnation Creek coho studies, and certainly the most widely cited, concerns the role of side-channels in over-winter survival. The early side-channel studies can now be seen as a specific indication of the more general importance of the wintertime to juvenile coho. To date, all of the important effects of logging have affected winter survivals, either directly in the case of physical effects or indirectly in the case of temperature effects.

A more philosophical conclusion, but an equally important one, is that the proper evaluation of the impact of a habitat perturbation on an animal population must include the entire life cycle. There are at least three components to this generality. First, it is apparent from the results that I have presented above, that looking at abundance of any two life stages can lead to diametrically opposed conclusions. Consider, for instance what conclusions are possible if adult returns were the only abundance estimate collected and then consider what conclusions would have been drawn from the smolt numbers alone. Second, it is also apparent that impacts on one life stage propagate through time. For instance, temperature increases in early spring led to earlier fry emergence, then to larger fingerling size, increased over-winter survival and so on. Finally, the time scale of any impact study must be based on the time scale of the processes involved. Five years for the study of post-logging impacts was an enormous span for research, yet it was barely adequate to give even an indication of the physical changes that are yet to come in the stream.

LITERATURE CITED

Allen, K.R. 1969. Limitation on production in salmonid populations in streams. In T.G. Northcote [ed.] Symposium on Salmon and Trout in Streams, p. 3-20. H.R. MacMillan Lectures in Fisheries, University of British Columbia, Vancouver, B.C.

Bilton, H.T., D.F. Alderdice, and J.T. Schnute. 1982. Influence of time and size at release of juvenile coho salmon (*Oncorhynchus kisutch*) on returns at maturity. Can. J. Fish. Aquat. Sci. 39:426-447.

Bisson, P.A., R.E. Bilby, M.D. Bryant, C.A. Dolloff, G.B. Grette, R.A. House, M.L. Murphy, K V. Koski, and J.R. Sedell. 1987. Large woody debris in forested streams in the Pacific northwest: past, present, and future, p. 143-190. In: E.O. Salo and T.W. Cundy [Eds.].Streamside management: forestry and fishery interactions, College of Forest Resources, University of Washington, Seattle, WA.

Bustard, D.R., and D.W. Narver. 1975. Aspects of the winter ecology of juvenile coho salmon (*Oncorhynchus kitsutch*) and steelhead trout (*Salmo gairdneri*). J. Fish. Res. Board Can. 32:667-680.

Grette, G.B. 1985. The role of large organic debris in juvenile salmonid rearing habitat in small streams. M.Sc. thesis, University of Washington, Seattle. 105 p.

Hartman, G.F., J.C. Scrivener, L.B. Holtby, and L. Powell. 1987. Some effects of different streamside treatments on physical conditions and fish population processes in Carnation Creek, a coastal rain forest stream in British Columbia, p. 330-372. In: E.O. Salo and T.W. Cundy [Eds.].Streamside management: forestry and fishery interactions, College of Forest Resources, University of Washington, Seattle, WA

Heifetz, J., M.L. Murphy, and K.V. Koski. 1986. Effects of logging on winter habitat of juvenile salmonids in Alaskan streams. N. Am. J. Fish. Manage. 6:52-58.

Holtby, L.B., and M.C. Healey. 1986. Selection for adult size in female coho salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 43:1946-1959.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Bd. Canada. 191:382 p.

Scrivener, J.C., and M.J. Brownlee. 1982. An analysis of the Carnation Creek gravel quality data 1973-1981, p. 154-173. In G.F. Hartman [ed.] Proceedings of the Carnation Creek workshop, a ten year review. Pacific Biological Station, Nanaimo, B.C.

Thedinga, J.F., and K.V. Koski. 1984. A stream ecosystem in an old-growth forest in southeastern Alaska. Part VI: The production of coho salmon smolts and adults from Porcupine Creek, p. 99-114. In W.R. Meehan, T.R. Merrell Jr., and T.R. Hanley, [ed.] Fish and Wildlife Relationships in Old-Growth Forests. Amer. Inst. Fish. Res. Biol., Juneau, Alaska.

Tschaplinski, P.J., and G.F. Hartman. 1983. Winter distribution of juvenile coho salmon (*Oncorhynchus kisutch*) before and after logging in Carnation Creek, British Colombia, and some implications for over-winter survival. Can. J. Fish. Aquat. Sci. 40:452-461.

van den Berghe, E.P., and M.R. Gross. 1984. Female size and nest depth in coho salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 41:204-206.

SOME PRELIMINARY COMMENTS ON RESULTS OF STUDIES OF TROUT BIOLOGY AND LOGGING IMPACTS IN CARNATION CREEK

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INTRODUCTION

This will be a very brief statement about some of the main results on studies of trout in the Carnation Creek drainage. The trout data are not completely analysed and so much has not been included in this paper.

THE FISH

There are two species of trout, steelhead and cutthroat (*Salmo gairdneri* and *S. clarki*), in Carnation Creek. The cutthroat are represented by resident forms, in the upper part of the drainage and some of the small tributaries, and by sea-run forms in the lower 3 km of the drainage (Figs. 1 and 2). There may also be resident cutthroat in the lower part of the stream. Cutthroat trout, marked above an impassable waterfall 3.4 km up Carnation Creek, have been recaptured in the lower part of the stream. As many as 30-40 fish may drop downstream each year. Up to 12 steelhead per year enter Carnation Creek. The adults do not migrate past the waterfall (Fig. 1) and the young steelhead are therefore distributed below the falls (Fig. 2).

OBSERVATIONS

There are problems with the trout population data which cannot be fully resolved and which impair the analysis of impacts of forest harvest on the trout. These involve difficulties in enumerating all adults, in determining species identity of the very young trout and in establishing the emergence time of fry. The methods of enumerating number of spawners and estimating numbers and sizes of young trout are described or referred to in Hartman et al. (1987). Several things have emerged from the analyses of data carried out to date:

1. Both species of trout used the small tributaries (<500 m long) that drain the 50 ha flood-plain in lower Carnation Creek (Brown 1985; Hartman and Brown 1987).
2. Cutthroat trout spawned in the small flood-plain tributaries, used them at all life stages and depended on them more than steelhead did.
3. The size of trout was controlled more by temperature than by density of trout or coho salmon. I conclude this for the following reasons:
    a. The size of cutthroat trout in a small side tributary of the lower creek and in the upper part of the main creek, above the impassable barrier, was correlated with the accumulated temperature units (CTU) in the stream where they reared (Figs. 3 and 4).
    b. The size of trout in these two parts of the drainage, and in two other streams was not negatively correlated with density of fish. In fact the evidence suggests that when fish densities were high in these streams the sizes were greater.
    c. In the lower part of the main creek size of trout was correlated with accumulated temperature units during March and April

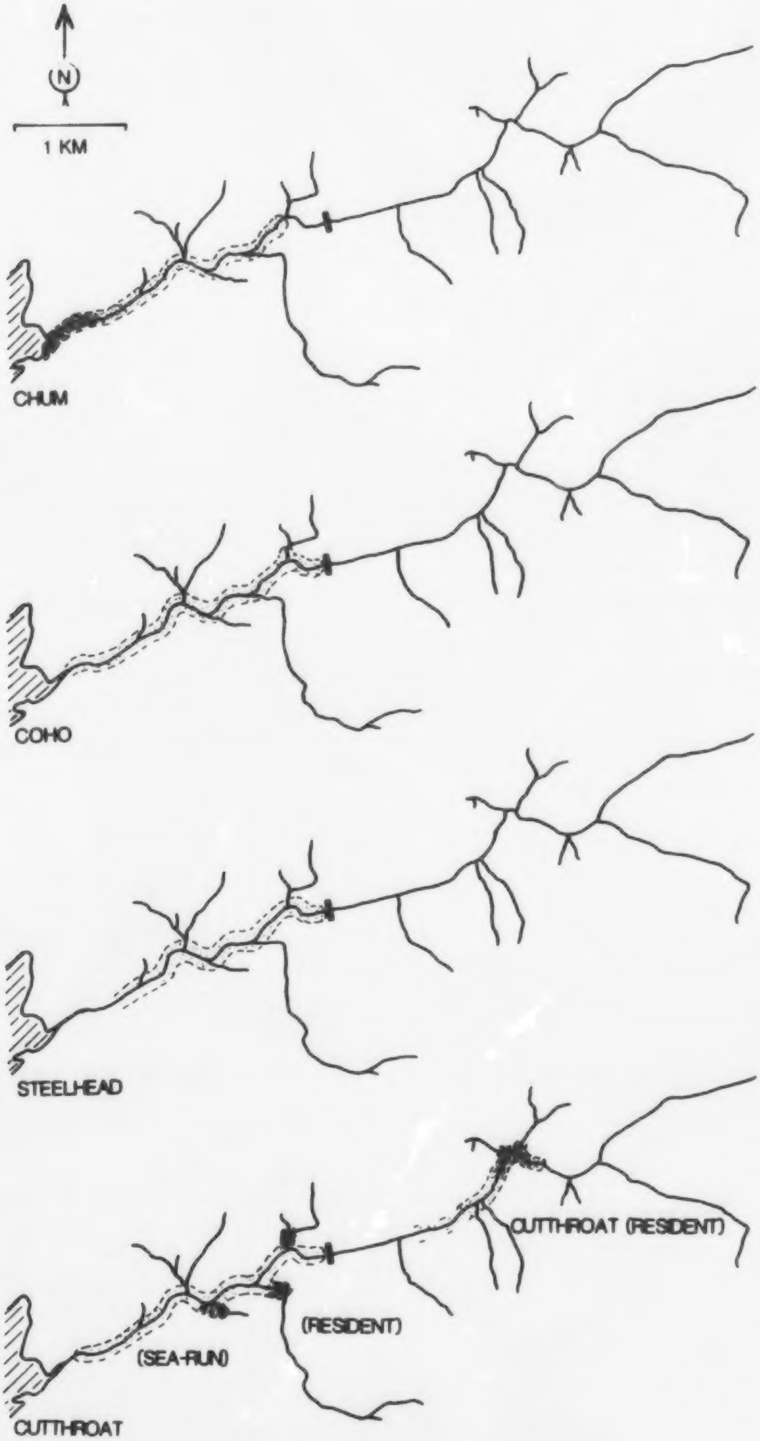

Figure 1. The distributions of adult salmonids in Carnation Creek and tributaries. Heavier stippling indicates areas of higher spawning density. The bar on the map indicates the approximate location of an impassable waterfall.

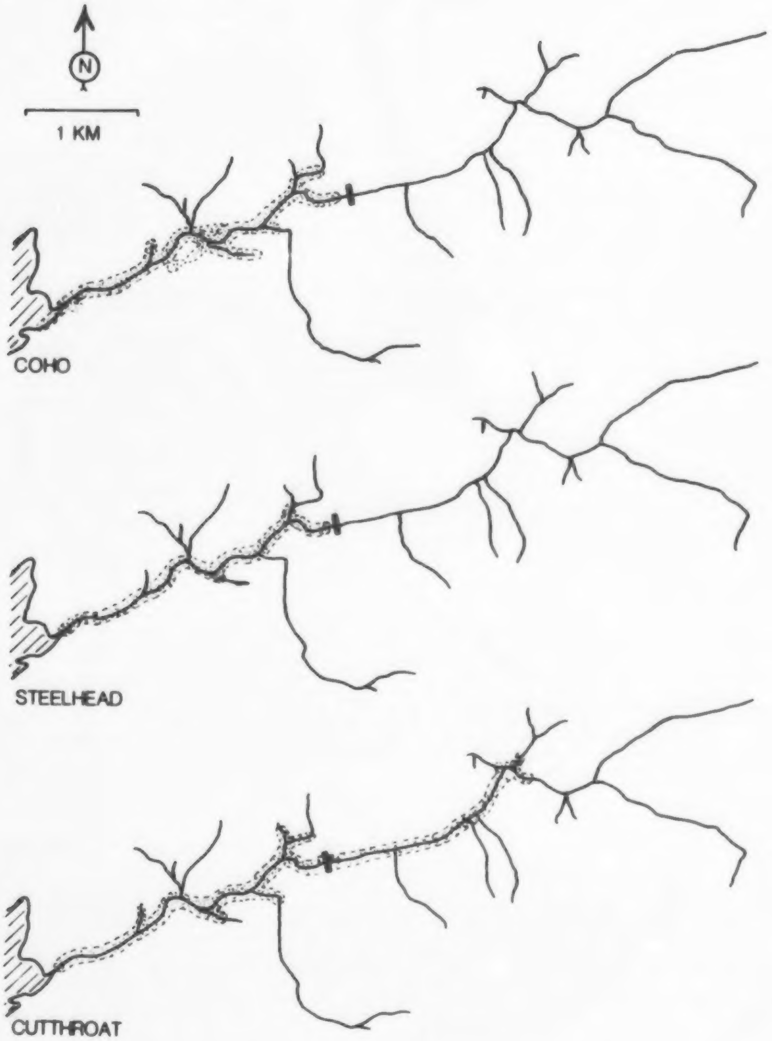

Figure 2. The distributions of young salmonids in Carnation Creek. Resident and sea-run cutthroat cannot be clearly separated. The bar on the map indicates the approximate location of an impassable waterfall.

(Fig. 5a), and also with accumulated temperature during the summer months.

d. In the lower part of the main creek the size of trout was not correlated with density of trout (Fig. 5b), or with density of coho juveniles (Hartman and Scrivener MS in preparation).

4. The estimated numbers of trout in the autumn population surveys were lower after logging began (Fig. 6).

5. Concurrent with the beginning of logging the number of steelhead smolts fell from the pre-logging range, of 100 to 500 fish, to less than 100 (Fig. 7). The number of cutthroat smolts was not lower, on average, after logging began.

6. The lengths of 0+ and 1+ trout, on September 30, were greater after logging than before. The sizes of the smolts were not greater (Hartman and Scrivener MS in preparation).

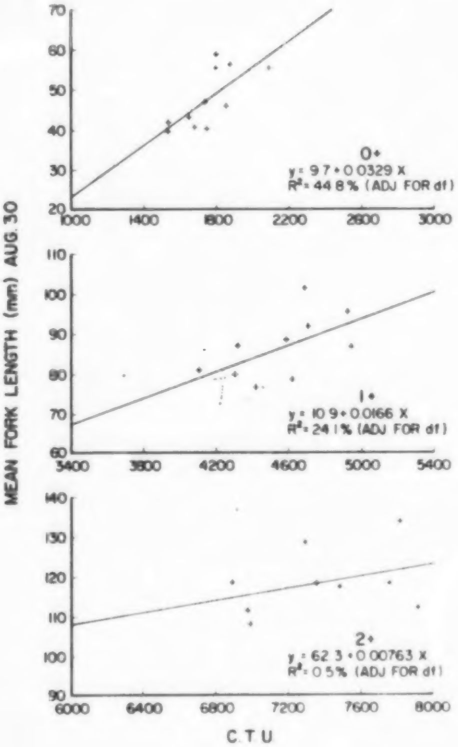

Figure 3. The relationships between lengths (August 30) of 0+, 1+, and 2+ cutthroat trout and total life summed thermal history (celcius temperature units, C.T.U.) in Tributary-C of Carnation Creek.

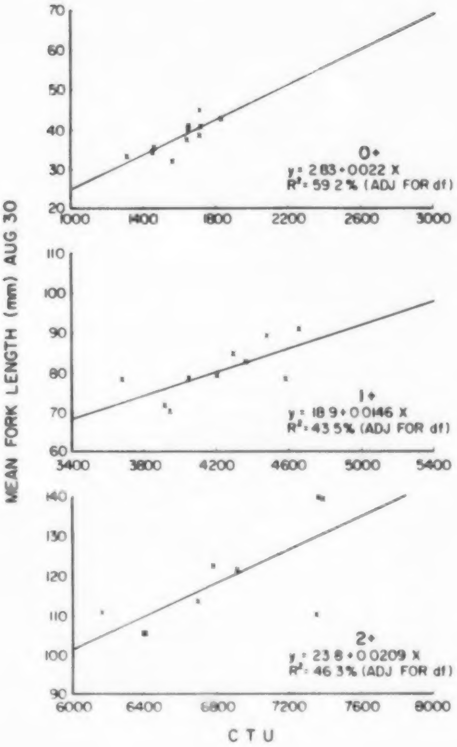

Figure 4. The relationships between lengths (August 30) of 0+, 1+, and 2+ cutthroat trout and summed thermal history (C.T.U.) in upper Carnation Creek, above an impassable barrier.

I offer the following speculation about trout population responses in Carnation Creek:

1. Deep pool habitat has become more shallow in Carnation Creek and in the section of stream from 1400 m to 3000 m upstream from the mouth, the volume of large debris has been reduced and its distribution has become more clumped. Bustard and Narver (1975) showed that juvenile steelhead, particularly the larger and older fish, became more closely associated with cover and deep water as the stream temperature declined during winter. The loss of pool depth and cover would adversely affect steelhead and would particularly affect the largest juveniles.

2. Cutthroat trout were more inclined to use of the small flood-plain tributaries than were steelhead. Many of them hatched from eggs in such habitat.

3. Because steelhead were more dependent on main-stem habitat, they were more vulnerable to the loss of cover and deep pools than were cutthroat or coho. I suggest that this difference between the biology of steelhead and cutthroat accounts, at least in part, for the difference in the patterns of smolt output between the two species (Fig. 7).

4. A second, unrelated line of evidence, suggests that the decline in steelhead smolt production may be related to conditions in the drainage basin. Coastwide abundance of wild steelhead as indicated by angler catch success (Gold and Somass rivers) and by numbers of steelhead entering the Keogh River has been higher since

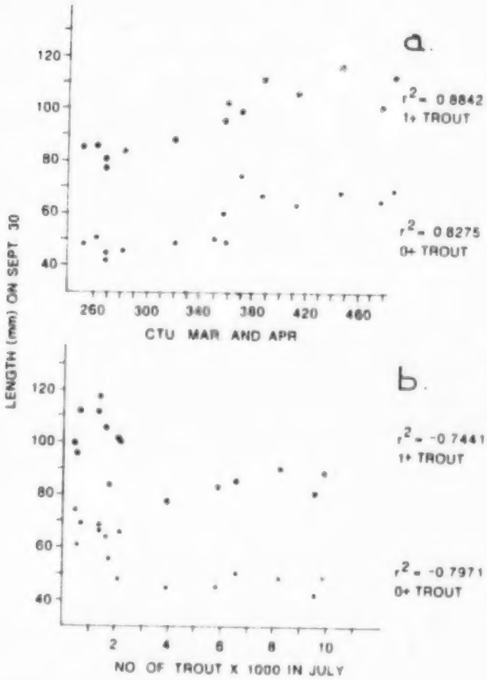

Figure 5a. Mean lengths of 0+ and 1+ trout (steelhead and cutthroat combined) vs. accumulated thermal history, March and April, in celcius temperature units in lower Carnation Creek.

5b. Mean lengths of 0+ and 1+ trout vs. density in lower Carnation Creek.

1979 (Hartman and Scrivener MS in preparation). This suggests that the decline in steelhead numbers in Carnation Creek is not a reflection of coastwide population changes.

MANAGEMENT IMPLICATIONS

1. In addition to maintaining indiginous populations of fish, upstream areas also contribute small numbers of cutthroat trout to downstream areas. Because of this, and because physical changes upstream may alter downstream areas, careful streamside management is important in upper stream sections containing small, resident trout.

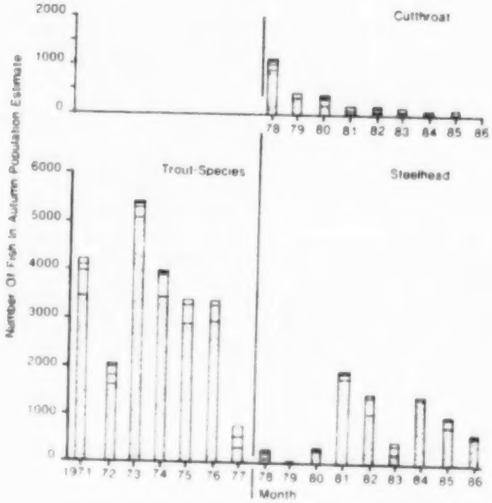

Figure 6. Estimated numbers of trout, during late September, in population surveys in the lower 3070 m of Carnation Creek. The stippled, lower part of each bar represents 0+ fish, the next three segments of the bar represent 1+, 2+, and 3+ (if present) fish. The two species of trout were counted together until 1977.

2. If drainages contain flood-plain areas and small (<500 m) tributaries on the flood-plains, such habitat may be important for production of trout species of as well as coho. The critical point in this regard is that such habitat should be identified and mapped during the wet season for the purpose of subsequent planning. These tributaries are not prone to adverse flooding and scouring so well planned forest harvest near them, should be possible.

3. Streamside openings allow light to enter the stream and elevate water temperature; and in some cases increase food production for fish. Well designed openings may increase the size of trout, but obtaining the benefit of increased light and stream temperature without channel degradation involves difficult planning compromises. Coastal streams such as

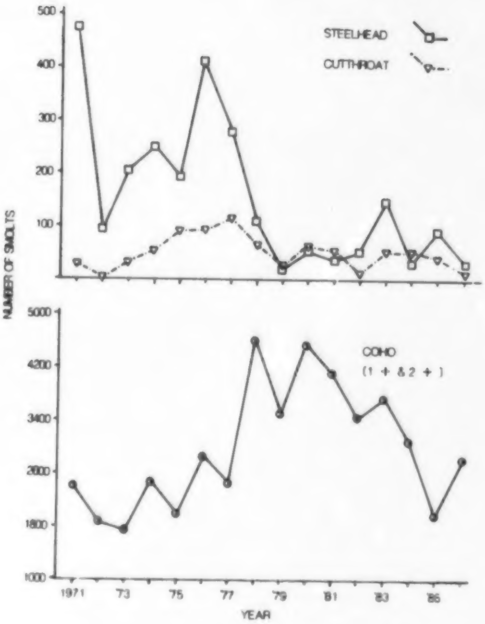

Figure 7. Numbers of steelhead and cutthroat trout; and coho salmon smolts leaving Carnation Creek from 1971 to 1986.

Carnation Creek are subject to severe natural freshets during winter. Because of this they may flush out large woody debris (winter habitat for fish) and scour spawning gravel if the banks or channels are disturbed. The maintenance of large debris and stable channel conditions are dependant on the streamside trees. It is crucial therefore to manage the streambank to retain the channel integrity and to provide an ongoing, long-term source of woody debris.

REFERENCES

Brown, T. G. 1985. The role of abandoned stream channels as overwintering habitat for juvenile salmonids. M.S. Thesis, Faculty of Graduate Studies, Department of Forestry, University of British Columbia, Vancouver, B.C. 134 p.

Bustard, D. R. and D. W. Narver. 1975. Aspects of the winter ecology of juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). J. Fish. Res. Board Can. 32: 667-680.

Hartman, G. F. and T. G. Brown. 1987. The use of small, temporary, floodplain tributaries by juvenile salmonids in a west coast rain-forest drainage basin, Carnation Creek, British Columbia. Can. J. Fish. Aquat. Sci. 44: 262-270.

Hartman, G. F., J. C. Scrivener, L. B. Holtby and J. Powell. 1987. Some effects of different streamside treatments on physical conditions and fish populations processes in Carnation Creek, a coastal rain forest stream in British Columbia, p. 330-372. In E. O. Salo and T. W. Cundy [eds.] Streamside Management: Forestry and fishery interactions. College of Forest Resources, AR-10, University of Washington, Seattle, Washington, 98195. Contribution No. 57. 471 p.

Hartman, G. F. and J. C. Scrivener. Forest harvest and processes of changes within a coastal stream ecosystem, Carnation Creek, British Columbia. MS in preparation for Can. Bull. Fish. Aquat. Sci.

PANEL DISCUSSION
SESSION 5: FISH POPULATION RESPONSE

RESPONSE BY D. CALLAS,
B.C. FOREST PRODUCTS, LTD.

After reviewing the 3 papers presented by Blair Holtby, Charles Scrivener and Gordon Hartman, and listening to today's and yesterday's presentations I find myself as an engineer and logging manager wondering what now do I do in order to put some of these results into practice, that satisfies my objectives and the objectives of other agencies involved with managing all the resources. And I stress the need to manage all our resources, not just timber or fish, but all resources.

Firstly I have a couple of specific questions directly related to the papers that I would like to comment on; what I expected, and what I think industry, both fisheries and logging, expects out of a long term study such as this.

Dr. Holtby stated that increases in spring water temperature brought forward the seaward migration of coho smolts by 7-14 days. As a result smolt survival decreased by 30%, largely negative. I would ask why this 30% loss?

The model results in Dr. Holtby's paper for years 11 and 30 years after logging are hypothetical and I would be interested to see what results are generated by being a little more optomistic and perhaps a little more realistic given that this is a west coast climate with the potential to produce very rapid regrowth of streamside vegetation include the 2nd crop of conifers, thereby creating a stable bank environment.

In Mr. Scrivener's paper he stresses the importance of gravel quality with regard to the chum fishery in the lower reaches of Carnation Creek. I wonder if the position of the "B" weir, which as I understand it held back some of the coarser gravels and prevented them from reaching the spawning grounds had an impact on the chum survival along with some of the logging related disturbances. I also note the time of emigration after logging is starting to fall back to the original April 15 date.

At the start of this workshop Mr. Young made 3 statements on objectives that we should strive to obtain.

1. Understand logging and fisheries interaction
2. Quantify the results
3. Communicate the information

Ladies and gentlemen I suggest that if we are to attain these objectives then we must put these results in a form that the day to day land and fisheries managers can understand and utilize. I find the results as presented very difficult to understand and to relate back to our day to day decisions. I believe we have to quantify all results based on our best knowledge. I see no quantity's or values lost or gained on either the logging side or the fishery side; the economics of the time require some quantification so all industries can survive. If we can quantify the results then this can be communciated to our respective staffs. I know that cost/benefit analysis is not an easy thing to come up with but I submit that after all the effort, time and money that has been spent on this project we should strive to get some good, useable, practical information to make all our jobs easier and provide the right decisions to manage our resources. Eventually the economics of the problem must help us to provide the decision. If any one of us, both industry and government are not prepared to discuss and try to quantify our situations, then we are not performing our job to its fullest. The communication of practical information is the most important item that we will all have to deal with when we leave here tommorrow.

RESPONSE BY M. WHATELY, MINISTRY OF ENVIRONMENT AND PARKS

The instructions put to me as a panel member for this session were to critique the papers, from the point of view of the way I operate in the real world. And what is the real world? The real world consists of forest managers, both government and industry, who are intent on doing their thing out there in the woods. Their thing, if I can grossly oversimplify for the moment, is to make damn sure that 50% of every dollar earned in B.C. continues to be forestry-related, countervailing duties and export taxes notwithstanding. Their job is to harvest trees as economically as possible, and as we all know, the best, highest-value trees are always those in the valley bottoms, right down there along side the rivers and creeks. I hasten to add however, knowing full well that every forester that I ever knew or worked with is probably sitting in the audience today, that foresters are as vitally concerned about proper management of their resource as fisheries managers are about theirs. But the real world, the one that my staff and I work in, is all about getting foresters to recognize that management of forests and fisheries is not mutually exclusive, that logging must be planned to accommodate fisheries for the simple fact that some streamside logging practices result in long-term devastation that can effect generations—and the time span I refer to is human, not fish.

So, having said that the real world consists of loggers intent on logging, how are thirteen years of study on coho, chum, and trout in Carnation Creek going to help us deal with streamside logging? Well, it seems to me that we knew all along what the effects of streamside logging on fish were—generally bad! However, the Carnation studies have given us the proof that we may have lacked a couple of decades ago. Now, I submit that it is up to the forester to view the proof for what it is worth, and plan his forest harvesting accordingly.

Each speaker has, in a different way, related to us several ways in which logging impacts on fisheries. Mr. Scrivener mentions, in terms of chum salmon, the observed reduction in egg to fry survival and the decline in fry size as a result of deterioration in gravel quality and permeability. He mentions the effect of post logging temperature changes on fry emergence and emigration, leading to possible increased predation in the estuary. The interesting point of this paper however, is in the discussion of the stock recruitment model. I won't delve into this subject too deeply, but suffice to say that five independent variables, of which I have mentioned three, were used to develop a model that predicts chum stocks pre and post logging. The predictions and observations were put in the context of possible commercial fishery openings, which is the real world I referred to earlier. Put simply, there were not many opportunities for a fishery during the immediate post logging years and predictions continue to show poor returns. Mr. Scrivener concludes that stocks affected by logging may be further adversely affected by natural processes entirely unrelated to logging or to the stock itself. My point is that poor logging practices have an impact on something beyond that which is immediately observable instream—another industry. You will recall Bill Young's remark yesterday that taken by itself, Carnation Creek and its fish populations may appear insignificant, but there are 100 Carnation Creeks in Barkley sound alone, and probably thousands, Coastwide. And you heard Norm Lemon's remark this morning—we're dealing with a multi-million dollar commercial fishery. It could be a multi-billion dollar industry.

In the coho paper, we heard Blair Holtby's explanation of the very complex interrelationships at work in Carnation.

(1) Coho smolt production is limited primarily by physical factors; i.e. gravel quality, flow conditions, availability of over-winter cover in the form of large debris and side channels, all of which are affected by logging.

(2) Logging affects temperature, which affects the critical timing of life history events which may or may not be negative, and of course, ocean survival. In Blair's modelling exercise, we see what I think is the most important conclusion—logging will have a net detrimental effect on coho production for 30 to 100 years. I harken back to the several occasions in past years when I have said in frustration—"We're banging our heads against the wall, let them log everything now—get it over with and get them out of the watershed so things can back to normal in a few years".

In terms of trout, Dr. Hartman mentions some items that are worth repeating:

(1) Steelhead trout juveniles require cover in the form of large debris, and deep water pools. The occurrence of both in Carnation Creek has

decreased, post logging.

(2) Cutthroat trout, and coho, require and use the small flood plain channels and tributaries that often go unnoticed when logging occurs, or is planned.

(3) Trout populations in headwater locations contribute recruitment to downstream areas. Such small populations should not be ignored regardless of their actual value as a fishery. The main connective thread throughout Gordon's paper was—with good pre-logging inventory and proper planning, streamside logging is possible.

On that note, I will end. But first, I will repeat an earlier comment. Fisheries biologists have done their homework—13 years of it. It is now up to the forest manager to accept the facts and act accordingly—manage the forest ecosystem, not just the trees.

RESPONSE BY RICK HIGGENS,
DEPT. OF FISHERIES AND OCEANS

A. Points of view

1. Biologist - My objective is to critique the work presented.

2. Manager - My objective is to apply the work presented.

B. As a biologist - I had difficulty in assimilating these results.

- Some of the information presented was extremely difficult for me to understand. Blair reported smolt and fry in terms of kg (biomass) but used counts for spawners and recruitments. I had trouble understanding the outcome but I am not refuting the scientific veracity of his data nor of its analysis.

- 100% smolt increase vs 30% decrease in oceanic survival. It would seem there is no free lunch.

- In Charlie Scrivener's paper I believe there is a contradiction in statements concerning decline in mean fry size. Some statement says size of emigrating fry did not decline until 1984 (Fig. 9). Next paragraph states mean fry size was affected by logging since 1976.

- Also, these papers have not related effects between different treatment areas, although such a comparison would be obviously beneficial.

C. As a manager

- We need to apply these results not simply file them away as so much intellectual communication to fire at industry and dazzle one another.

- Our job is to take information and feed our fisheries officers so they can make decisions.

- Also our group's job to stand ready to technically assist our officers.

- We also are responsible for justifying our constraints to industry.

D. No F.O.'s, forestry people represented here

- If you have been listening to speakers, there are very few from the forest side, no fisheries officers, mainly consultants and researchers.

- Why? They already have this, they don't understand it, or they don't care.

E. Application model

- Applicability of 13 years of such intense research labour is now the major issue.

- Otherwise it is still them (rapers and pillagers) against us (defenders of the public faith).

- Alevin mortality must be explained.

- We owe it to each other to take these results and put them into guidelines in a useable format.

QUESTIONS
SESSION 5: FISH POPULATION RESPONSE

Moderator: G. Taylor

WYNN HAYES: I have a question for Gordon Hartman.

You reiterated the importance of floodplain for over-wintering coho and trout and I'm just wondering how does this affect silvicultural use on the floodplains as well as development of buffer strips? What are your recommendations for management here?

DR. HARTMAN: I think that in the Carnation Creek system the floodplain tributaries are resiliant but they have already been able to be subjected to yarding across them and through them and so forth and still sustain numbers of fish so I think that it should be possible to to carry out silvicultural activities close to them, but I would not recommend at this stage that the silvicultural activities destroy the vegetation at the sides of those tributaries nor that they do in or destroy the rooted vegetation to which Tom Brown referred that you have in the tributaries which may be holding the productive muck bottom together in those systems. So up to the edges, but after that, not into them, and I think leave that vegetation at the side of them.

MS. HAYES: You have no further recommendations for precise development of buffer strips in that area?

DR. HARTMAN: Not for precise development of buffer strips and in point of fact I'd like to comment on that. I'm hesitant as a research person to give an answer to your question and maybe I'm going to second guess what I'm going to say tomorrow and that is, I don't think it's up to us to tell people exactly what they are supposed to do.

What we're trying to do is tell you how the system works and I think that if the people who are out there on the land doing the managing haven't got the wherewithall to read papers and make some interpretations and make some decisions on the basis of what they know and what they have seen and what they have lived with, then they ought to get off the thing and let somebody else in who can. But I honestly don't think that it's a research person's place to start making specific recommendations. I think it's up to us to tell you how the system works, what you might expect if you do this or do that.

But beyond that I'm reluctant to make recommendations on the basis of one system because in point of fact I know that if I do that, I'm presumptuous enough to do that about other systems; I know that people like Morrison, Brownley, and the guys that have been out there for a long time will understand very well what the exceptions are and why I should not make the specific recommendations I'm doing, what the pitfalls are.

And I would say I would rather give them the information and let them make the decisions. So maybe I can tell you if you're looking for me to come with a whole bunch of specific recommendations tomorrow, stay in bed or have your second cup of coffee.

MR. TAYLOR: I think in fairness to what Gordon has said, you should realize Gordon and Bill have been very much involved along with 90 other experts in the field, if you like, in developing guidelines and talking about those distances so we're not holding the researchers entirely true to millimicrons per dynes squared; they're part of the process.

TED HARDING: Charlie, one question. Blair Holtby in his presentation recognized the problem of ocean survival and you didn't mention that. Am I correct you didn't mention that particular account with your chum survival?

MR. SCRIVENER: No, in the chum model one of the major items is the ocean survival aspect in which I try and utilize salinity abnormalities as an indicator of that ocean survival; it's the important step. And the crucial thing here is that the influences over the last couple of years have occurred mainly because of the changes in the ocean survival but they have been coupled with the very poor indicator and problems within the freshwater part. The two coupled together have produced a massive variability and the serious problem for the stock.

The crucial point in the whole thing is that you cannot isolate individual impacts, you have to integrate them in an ecological system. And the observed impacts that we've seen from logging when they are integrated into these particular models, they essentially appear to make it far more difficult to manage that stock. We have to know better information, and we have to make tough decisions on how we manage that fish stock to maintain it.

MR. DE LEEUW: I have a question for Blair Holtby. Was I correct in understanding that there's a 60 to 70 per cent exploitation rate on adult coho through the commercial fishery?

DR. HOLTBY: Yes.

MR. DE LEEUW: My question is how did you derive that number and the other thing is that had those fish in fact spawned in Carnation Creek, how big an effect do you think the juveniles would have had on the results of research that's being carried out on coho juveniles in Carnation Creek?

DR. HOLTBY: I can answer the first part easily, that the exploitation rates were derived from the same coded bar tag releases from Robertson Creek hatchery and I believe the exploitation would be close to those actually felt by the Carnation Creek population.

MR. DE LEEUW: So you're assuming that the Robertson Creek coho behave in much the same fashion as adults in the ocean as do the Carnation Creek ones?

DR. HOLTBY: Yes. Your second question is difficult to answer. If I understand it correctly, what would have happened had all of those adults escaped, and arrived back at Carnation Creek. There obviously would have been a lot more fish there. The obvious result would have been that there would have been far greater emergence and we would have had many more observations with large numbers of fry in the creek and many fewer with smaller numbers at the creek. And the only thing I can suggest is it would have been more difficult to detect or more difficult to determine the form of the relationships than it was because we had a rather large escapement over in both pre logging and the post logging period so it was fortuitous that the escapement range was quite large in enabling me to tease out the underlying processes. If you have absolute constant behaviour, the same number of fish arrive at the creek year after year, you essentially have no variability and that variability is the stuff of statistically teasing out what the underlying processes are.

DR. CEDERHOLM: I'd like to follow up that question with one for Blair. What would have happened in Carnation Creek if he didn't have a 60 to 65 percent exploitation rate but more like a 90 to 95 percent on your coho stocks. Under all the conditions?

DR. HOLTBY: There wouldn't be any coho there. If my modelling is correct -- and I noted Rick Higgins challenged my numbers -- if my modelling is correct, then the coho population could not sustain a 95 percent exploitation rate for more than a couple of years. It would rapidly be extincted.

DR. CEDERHOLM: What about the effects of logging as they are in the channel, would that have accelerated that decline?

DR. HOLTBY: Yes. Because the stock productivity is falling as overwintering habitat is disappearing. Survival rates through the winter are decreasing so stock productivity is falling; and at any time you increase exploitation rates, terminal harvest rates, and stock productivity falls, that will just drive the population down faster.

DR. CEDERHOLM: That just reminds me some of the situations we have south of border, and we may even have those situations in British Columbia, maybe some of your isolated streams depending on where the fishery is located, how mobile the fishery is, and what particular characteristics describe the fishery.

In the Clearwater River system that I'm working on we have had an adult population roughly of the size of one of your populations in Carnation Creek, and it's a

150 square mile watershed. We calculated the exploitation rates well up in the 80 or 95 or better percent levels and in considering the coastal drainages and their dynamics and their nonpredictable difficult winters as you guys have pointed out, when you have these kinds of exploitation rates in conjunction with what impacts do come from logging and on top of that you have unpredictable natural variability, I think that we have a real problem when we think we can log and maintain these exploitations. I think we need to see some moderation on both sides. We need to not only see some cutbacks in our fishery but also start exercising some streamside management activities that incorporate some of the suggestions that have been discussed and on both sides come together and make some efforts to do what it takes to protect those fisheries resources.

JOHN LAMB: My question's for superstar. Charley, most of the chum spawning occurs below the fence and I'm just wondering how you obtain those precise numbers on fry escapements and adults returning in they that all occurred below the fence.

MR. SCRIVENER: The adult escapement information is the total run. It's fairly easy to count these kind of fish if you spend a lot of time in the stream when they're actually out there spawning; they're out there spawning in the middle of the day, they spread themselves out a little. It's not too difficult to get a pretty accurate count on the escapement.

The second item, we have emergence traps on the estuary in which we've got timing from day one, and the timing figures we have are not just the counting fence but the two coupled together, timing of emergence in the estuary coupled with timing emigrations through the counting fence. The egg-to-fry information is based purely on the egg-to-fry information above the counting fence which is only up to 25 percent of the run but the indications on emergence from the estuaries and the gravel quality in the estuaries is suggesting the same sort of thing is occurring upstream as downstream.

JOHN LAMB: Thank you.

MR. SCRIVENER So it's in the ballpark. Well, a very accurate ballpark.

RON DIEDERICH: Fish and Wildlife. I guess my question really should be directed to senior managers like Peter Akhurst and Mike Whatley and Rick Higgins. What I see here, I mean I am presuming that I understand since I work in habitat management and I know I interact with a lot of the foresters here, I presume that I understand some of the fish processes that go on and I can see from the Carnation Creek information that there's a lot of specific research results and, as somebody pointed out, there's a lot of exceptions up and down the coast. My problem, and I can see a real value is, my question has to be can we develop something that takes all the synthesis of Carnation and all the other work that's been done and write out a handbook that describes the changes in the stream environment and the changes in the fish population on a general basis.

What we seem to have is we seem to have the really particular research studies that Jeff Cederholm's done in his part of the world, the Alaskan's have done in their part of the world, and we've done in Carnation, we seem to have the guidelines which say do this, do that, and do the other thing, what we don't seem to have in the middle is because of all these research results, we don't seem to have something that says here is the general way the stream and the fish populations work for everybody to understand.

I mean, I feel that I can get some of that out of the Carnation Creek results and some of the other stuff that I've read but I'm not sure that all the foresters and engineers can separate those things out, and I understand that in some of the wildlife things that are being worked on right now -- right now we're working on a wildlife forestry conflicts handbook as well -- and one of the integral parts of that is how wildlife work, how forests work, and how the things interact and I think something that would be really valuable is how streams work, how fish work, and in a very general fashion, that would bridge the research and the guidelines and I'm wondering, you know, either Peter or Rick or Mike, can we develop a handbook that gives a general picture of the way streams and fish work that would be more useful to everybody else. As Rick said something that we can all digest.

MR. SCRIVENER: I'd like to take a stab at that. There are handbooks all over the place obviously not being read. Brownley and Toews spent a long time in developing an extensive handbook that is well written in laymen's language. I would suggest that you read it.

JACK DRYBURG: I'd like to address this to Blair Holtby. We've been dealing with a bit of an artificial situation to a certain extent here at Carnation Creek.

The artificial situation is that we introduced logging practices that are not normal practices. The intensive treatment never was during the time of logging, is not, nor will be normal practice. Now, if Carnation Creek had been logged according to normal logging practice with the leave strip from the canyon down to the estuary, leaving large organic debris intact, and all the other various things that we would have had with the normal leave strip scenario, what would you see or would your model show possibly as far as our coho populations today?

DR. HOLTBY: I'll answer that in two parts. The first is that I would basically preface that by limited experience, very limited experience but my understanding of why the Carnation Creek project was first started was that David Narver in particular was concerned with his perceptions of the responses to streams in quote "normal logging practices," and those responses from what has been described to me were very similar to what we've seen at Carnation so I would essentially dispute your claim that the logging that was done at Carnation was not normal operational logging.

I think that you in your panel response earlier essentially summed up what is to me staring us all in the face, the solution to the perceived problem. If the canopy over the stream at Carnation had been thinned so that temperature response that I observed was present and if a substantially better designed leave strip had been left, that would protect the integrity of the stream bank and would have permitted the provision of large debris for the next century or so, then the situation that would now be seen at Carnation Creek would be an abundance of coho and the probability that that abundance would remain for the next 50 to 100 years.

MR. DRYBURG: Just one point of clarification about normal logging at that time. Specifically we would not have been allowed to do the cross stream yarding and whatever we did do at that time. We would have not obtained approval from the Ministry of Forests.

DR.HOLTBY: I appreciate that, but my understanding of stream processes is that by cross stream yarding and removal of the large debris, all that was really brought about was a more rapid deterioration of the stream. The same sort of channel destablization, stream wandering and widening does occur with normal operational practices. It just takes longer to appear.

JEFF DAVES: Okay, my question is related and it's also for Blair. Would your model be amenable to, say your model showed that the temperature changes and the bank stability changes were particularly important whereas the gravel changes were less important, would it be amenable to looking at different logging plans with different, say half the amount of stream that was impacted by the logging proposal, and make certain habitat inferences from that and then look at population effects; is it in essence amenable to looking at various logging strategies?

DR. HOLTBY: In a word, maybe. I think so if I understand your question. But there are some functional relationships which would have to be better quantified.

MR. TAYLOR: I know, Peter, the one question you asked is when are the guidelines going to come out. I would hope we would get by the mid morning tomorrow some indication from the people in charge that the guidelines are on their way. And secondly I would really support the idea that if we've got people who can't read technical journals, that maybe internally we should be providing some kind of four-letter writedowns, if you'd like, of Carnation Creek so that these people can in fact get on with their jobs.

MR. YOUNG: Thanks, Gerry. I just can't resist making one comment here before we wind up. We have heard more and more about fisheries, and that's true, and being a real dumb general forester, born and bred just north of Spuzzum, I probably have a greater potential of learning than anybody else but it takes two to tango and you just don't accept in integrated resource management that there's stumpors and stumpees, as they say.

I think it's more than fisheries and foresters. Every resource manager be he an fisheries manager, a forest manager, a wildlife manager or a recreation manager must commit himself to learn more about everybody else's resource and that combination of knowledge which we're getting today, that combination of knowledge with good communication amongst us all, which we have today, is where the answer will be so I've just heard some things that bothered me a bit, that the foresters have to learn a bit more about everything else and everything else will be saved. I think we all have an obligation for every resource manager, and it's more than just fisheries and forestery people, we should bring in range management in the interior and wildlife management, and the complexities of the diversity that we have.

And if I go one step further, there is no place else in the world except maybe just south of the line, our American cousins, that have the ecosystem complexity that we have. If I could only be in the southeast states and manage deer, loblolly pine and sage pine, or if I could be in Sweden and manage spruce, moose, and pine I would be happy.

I would say that in British Columbia, and maybe including our friends south of the line, we have more ecosystem change in one valley, one major drainage, than they would have in the whole country or region in those areas and so therefore with that diversity we have a complexity in this region that is unequal. We have Canada's most diverse wildlife, an important wildlife resource, Canada's most diverse and important timber resource, and one of the world's most important fisheries resources.

Add to that the complexities of topography and climate and I say we have a challenge and we must take that challenge and learn more about the other resource values; I am getting on my high horse here but I'm saying that there's an obligation on all of us to do that.

SESSION 6: SYNTHESIS

Moderator: G. Ainscough
MacMillan Bloedel Ltd.

CARNATION CREEK, 15 YEARS OF FISHERIES-FORESTRY WORK, BRIDGES FROM RESEARCH TO MANAGEMENT

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ABSTRACT

This paper presents a brief integration of major components of a 16 year, multi-disciplinary, fisheries-forestry study. It discusses the use of the results in land management. It stresses that land managers must be able to apply the general understanding of ecosystem processes to more specific elements of planning on a system by system basis.

INTRODUCTION

The results from key components of the Carnation Creek study have been presented elsewhere in the proceedings of this workshop. Because of severe time constraints during writing, this paper will not review some parts of the work at all and will cover other parts only briefly. A more extensive review and integration of the Carnation Creek work is in preparation (Hartman and Scrivener, MS). Details of the logging plan and its timetable are discussed earlier in the proceedings (Scrivener 1988a). This paper integrates the main results from the study to show the effects of physical conditions on the biological features of the system and to show the interactions of different physical conditions on fish production within the watershed. The syntheses as it stands is a mosaic which contains well established relationships and processes at some points and speculation or weakly supported conclusions at others. Incomplete analysis and write-up prevent an over-all synthesis.

PERCEPTIONS ABOUT IMPACTS

During the period in which Carnation Creek research workers have dealt with processes in the system a number of perceptions about logging and fisheries have been developed. These are implicit in the schematic models of processes which will be presented later. They must also form the basis for both planning and analysis of forest harvest activities by managers. It is recommended that the following points about the effects of forest harvest on a watershed system be kept in mind by resource managers:

1. Different forest harvest and silvicultural activities cause different physical changes in different parts of a drainage ecosystem. As an example, the changes and the nature of the changes in the Carnation Creek system are indicated in Fig. 1.

2. The changes, which may involve increase in some variables or decrease in others, may have

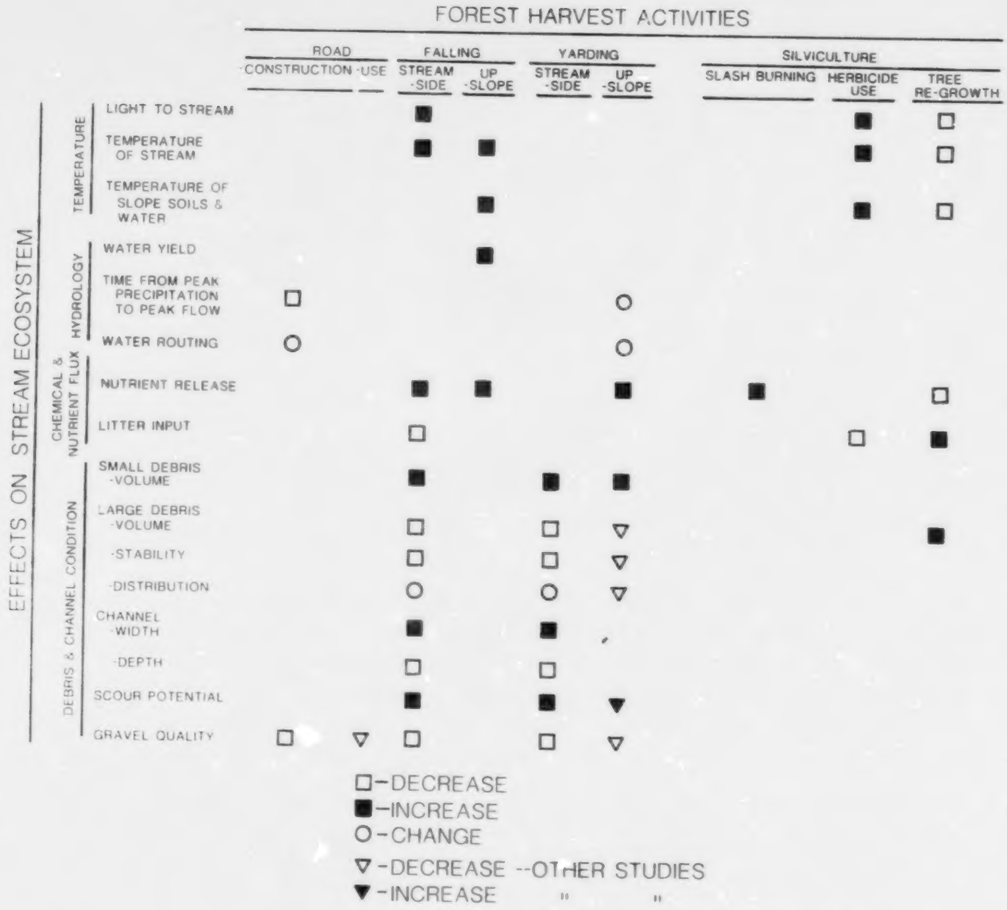

Figure 1. A matrix of logging activities and effects on physical conditions in Carnation Creek. Some effects of logging activities, from studies in the Queen Charlotte Islands and the Olympic Peninsula (indicated by triangles), are included to illustrate differences between geographic areas.

positive, or negative, or neutral effects on fish depending on the species and life stage.

3. The effect of a physical change caused by logging may also be positive or negative depending on the scale of the activity.

4. The effect of an activity, and subsequent physical changes, on fish may depend also on the understanding of the site sensitivities that was shown in preparing the logging plan and the degree of care taken in following the plan.

5. Most of the changes in physical conditions in Carnation Creek were related to streamside activities (Fig. 1).

6. The time scales, over which physical responses to logging activities occur, vary depending on the activity and subsequent storm frequency and intensity. In Figure 1, the changes in light intensity on the soil, on the temperature of stream water and on nutrient loading were almost immediate following forest harvesting. The changes in large debris condition, channel structure and gravel quality developed over 2 to 5 years. The second round of changes in light intensity, at stream and ground level, and stream temperature (Fig. 1) will occur one or two decades later with canopy re-growth. These changes will reverse the immediate post logging trend of light and temperature increase.

BASIN PROCESSES AND IMPACTS

Logging activities in the Carnation Creek basin have produced changes in hydrological conditions, debris volume and stability, channel configuration, gravel quality, insolation of the stream, stream temperature regimes, and fish food production conditions. The impacts of these changes in some cases enhance fish production and in other cases reduce it.

In the following section of the paper I will present four schematic diagrams which review hydrological, geomorphological, thermal, and trophic processes in the system. The diagrams integrate the major conclusions found, or relationships demonstrated through work represented in the background papers of this workshop. Where conclusions have been firmly established in background work, such has been indicated in the diagram by enclosing the statement in heavy outline. Where a cause-and-effect relationship has been firmly established it too has been indicated by using a heavy line arrow between statements. If conclusions or cause-and-effect relationships are tenuous or supported only by research done elsewhere the lines around and joining statements are light and dashed, respectively. Statements that indicate an effect on fish are accentuated by stippling. Figures 2, 3, 4, and 5 stand alone as very brief descriptions of processes within the system. The processes are reviewed and discussed in Hartman and Scrivener, (MS), and the relationships underlying the most important components in each diagram have been reviewed elsewhere in these proceedings.

There are 4 points that should be noted in connection with Figure 2 and Carnation Creek hydrology:

1. Roads altered water routing and thus changed rate of run-off and, in some locations, slope stability in a sub-basin of Carnation Creek.

2. Clearcutting 41% of the total basin did not detectably alter water yield or run-off pattern. Gravel build up around the main flow gauging weir reduced the accurracy of discharge measurements. If there were changes, they were smaller than this source of error.

3. We cannot identify hydrological changes, caused by logging, that had major impacts on fish. However, elevation of ground-water levels are presumed to have a positive effect on fish production in flood-plain habitat during summer.

4. Carnation Creek is, in a hydrological sense, a high energy system. With or without logging-related changes, the hydrological conditions may have greater direct and indirect effects on fish in this biogeoclimatic zone.

There are 7 points that should be noted with regard to the responses of woody debris and stream channel conditions to logging (Fig. 3):

1. The careful and intensive treatments produced the same conditions within the channel. The main difference was that it took longer for the changes to occur following the careful treatment.

2. The channel on the alluvial flood plain has become and continues to become wider, straighter, and more uniform. There is particular need to manage the flood plain sections of streams to prevent this process.

3. Changes in gravel quality were related to changes in debris stability and bank erosion rates in the intense treatment.

4. Changes in gravel quality occurred 2 and 5 years after logging in the upper and lower layers of gravel respectively.

5. The changes in gravel quality occurred 1 km downstream from the careful and intensive treatment sections.

6. The addition of logging debris and the break up of natural debris in the stream produced temporary higher densities of rearing salmonids. This debris was removed during subsequent freshets and their densities declined.

7. Most of the changes in debris condition, channel form and gravel quality ultimately had negative effects on fish where impacts were detected.

Although it is not dealt with in Figure 3, debris torrents and sediment movement from the steep slope tributaries and the canyon section of the stream, have resulted in deposition of large but unquanitified volumes of gravel in the stream channel in the upper end of the flood plain. This material will be sorted and re-deposited downstream in future years.

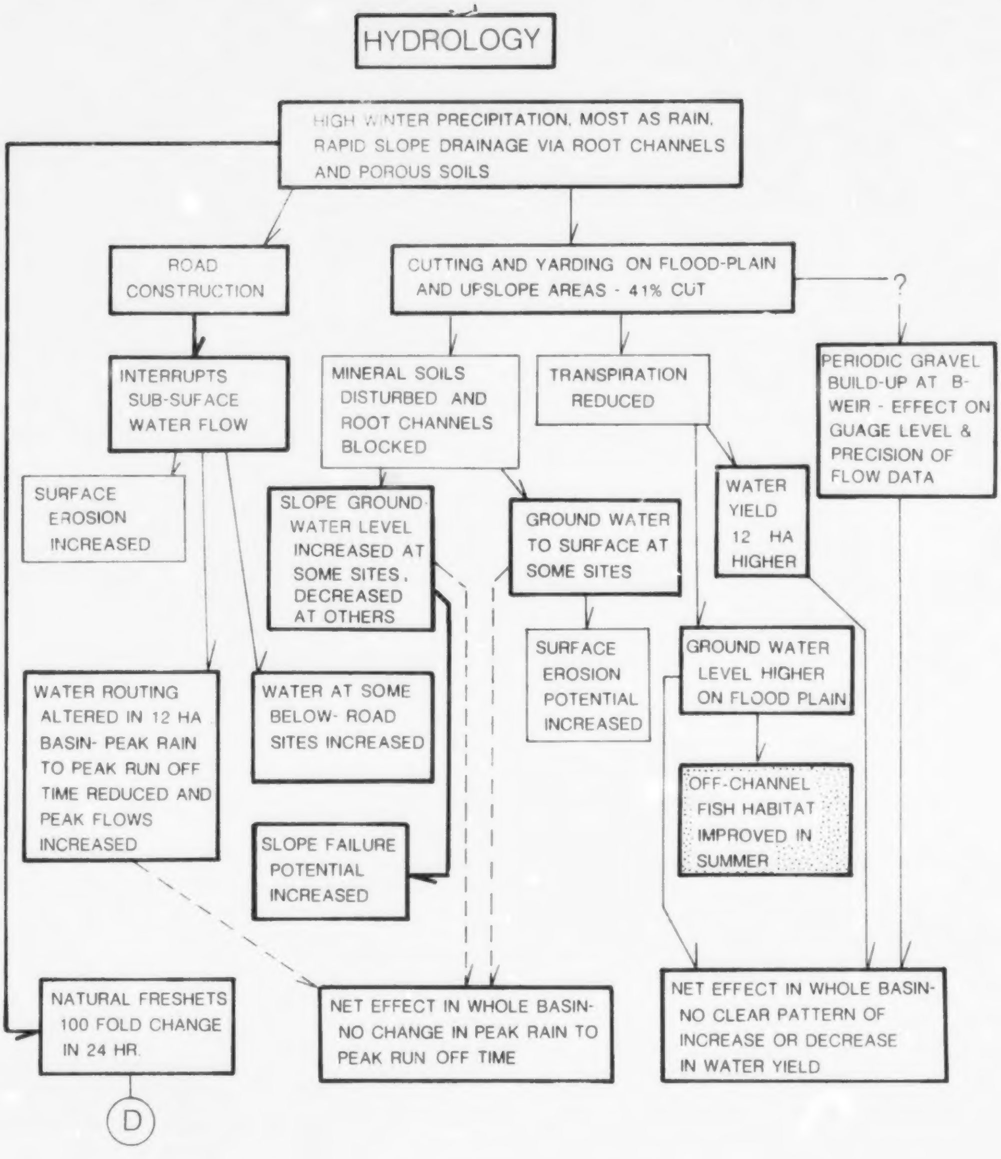
HYDROLOGY
HIGH WINTER PRECIPITATION, MOST AS RAIN, RAPID SLOPE DRAINAGE VIA ROOT CHANNELS AND POROUS SOILS
ROAD CONSTRUCTION
CUTTING AND YARDING ON FLOOD-PLAIN AND UPSLOPE AREAS - 41% CUT
?
INTERRUPTS SUB-SUFACE WATER FLOW
MINERAL SOILS DISTURBED AND ROOT CHANNELS BLOCKED
TRANSPIRATION REDUCED
PERIODIC GRAVEL BUILD-UP AT B-WEIR - EFFECT ON GUAGE LEVEL & PRECISION OF FLOW DATA
SURFACE EROSION INCREASED
SLOPE GROUND-WATER LEVEL INCREASED AT SOME SITES, DECREASED AT OTHERS
GROUND WATER TO SURFACE AT SOME SITES
WATER YIELD 12 HA HIGHER
SURFACE EROSION POTENTIAL INCREASED
GROUND WATER LEVEL HIGHER ON FLOOD PLAIN
WATER ROUTING ALTERED IN 12 HA BASIN- PEAK RAIN TO PEAK RUN OFF TIME REDUCED AND PEAK FLOWS INCREASED
WATER AT SOME BELOW- ROAD SITES INCREASED
OFF-CHANNEL FISH HABITAT IMPROVED IN SUMMER
SLOPE FAILURE POTENTIAL INCREASED
NATURAL FRESHETS 100 FOLD CHANGE IN 24 HR.
NET EFFECT IN WHOLE BASIN- NO CHANGE IN PEAK RAIN TO PEAK RUN OFF TIME
NET EFFECT IN WHOLE BASIN- NO CLEAR PATTERN OF INCREASE OR DECREASE IN WATER YIELD
D

Figure 2. A schematic diagram outlining hydrological relationships and responses to logging and road construction. The capital letter D, T, or P on the diagram indicates the location of an important interaction with Debris, Temperature, or Production related processes. Light or dashed lines indicate relationships established during other studies.

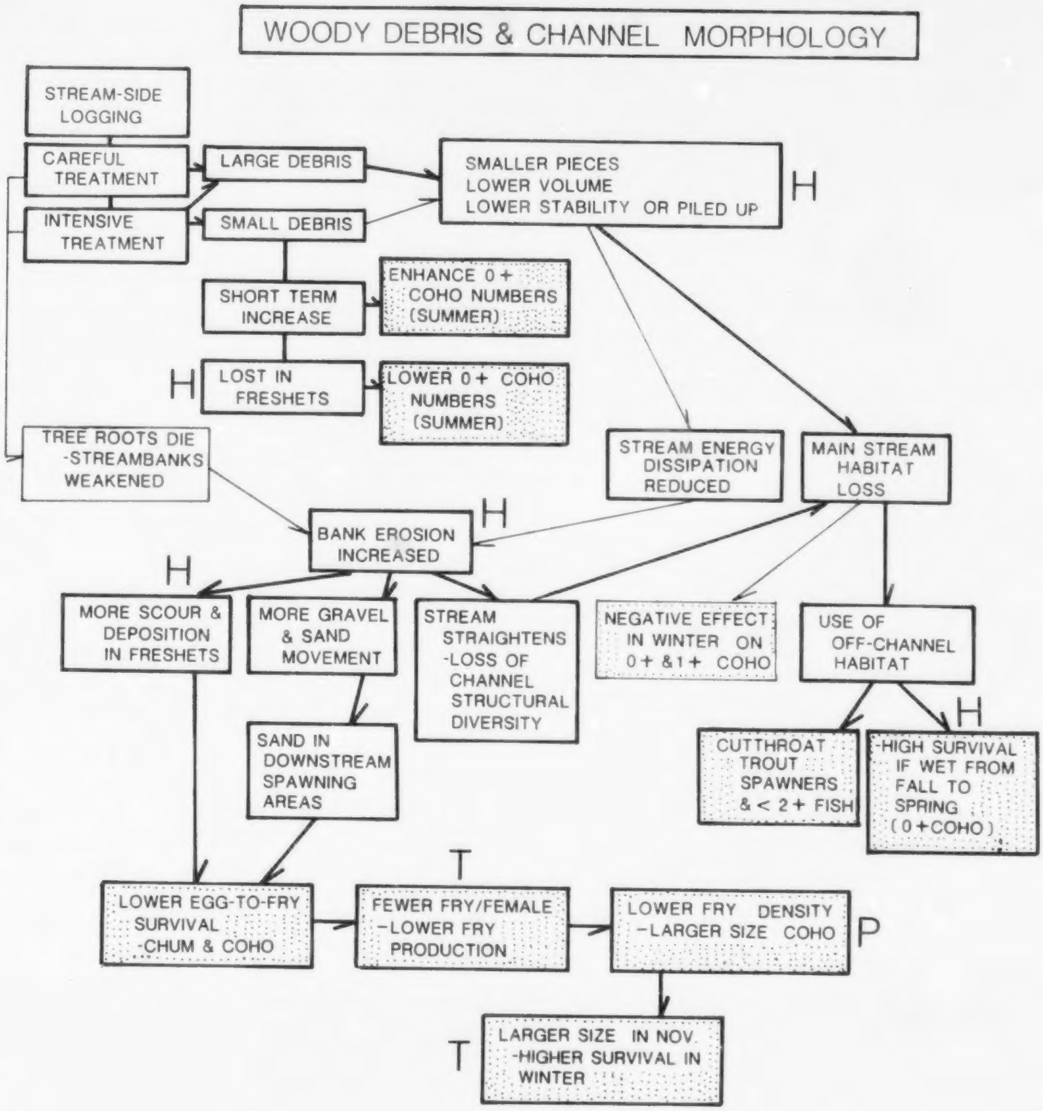
WOODY DEBRIS & CHANNEL MORPHOLOGY
STREAM-SIDE LOGGING
CAREFUL TREATMENT
INTENSIVE TREATMENT
LARGE DEBRIS
SMALL DEBRIS
SMALLER PIECES LOWER VOLUME LOWER STABILITY OR PILED UP
H
SHORT TERM INCREASE
ENHANCE 0+ COHO NUMBERS (SUMMER)
H
LOST IN FRESHETS
LOWER 0+ COHO NUMBERS (SUMMER)
TREE ROOTS DIE -STREAMBANKS WEAKENED
STREAM ENERGY DISSIPATION REDUCED
MAIN STREAM HABITAT LOSS
BANK EROSION INCREASED
H
H
MORE SCOUR & DEPOSITION IN FRESHETS
MORE GRAVEL & SAND MOVEMENT
STREAM STRAIGHTENS -LOSS OF CHANNEL STRUCTURAL DIVERSITY
NEGATIVE EFFECT IN WINTER ON 0+ &1+ COHO
USE OF OFF-CHANNEL HABITAT
H
SAND IN DOWNSTREAM SPAWNING AREAS
CUTTHROAT TROUT SPAWNERS & < 2+ FISH
-HIGH SURVIVAL IF WET FROM FALL TO SPRING (0+COHO)
T
LOWER EGG-TO-FRY SURVIVAL -CHUM & COHO
FEWER FRY/FEMALE -LOWER FRY PRODUCTION
LOWER FRY DENSITY -LARGER SIZE COHO
P
T
LARGER SIZE IN NOV. -HIGHER SURVIVAL IN WINTER

Figure 3. A schematic diagram outlining the effects of logging activities on debris and effects of debris change on channel conditions and fish. An H, T, or P on the diagram indicates the location of an important interaction with Hydrological, Temperature, or Production related processes. See text for explanation of line density differences and stippling.

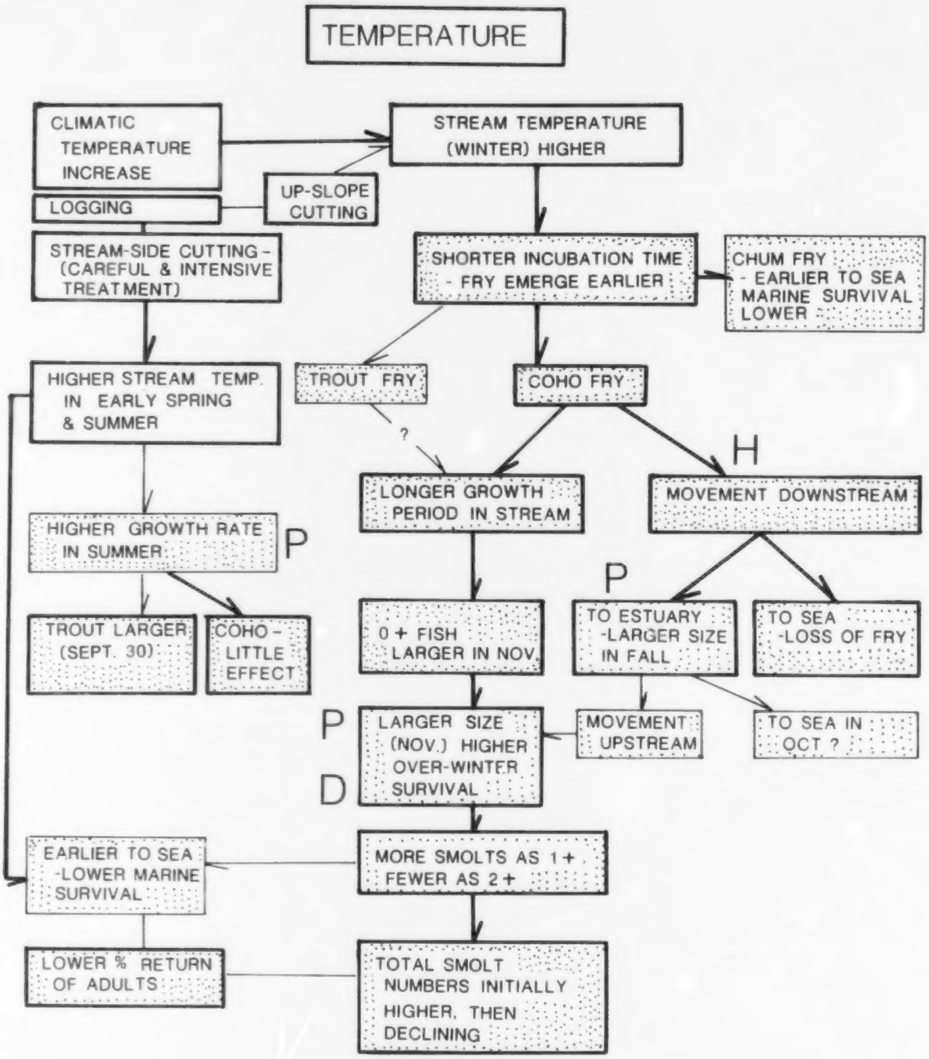
TEMPERATURE
CLIMATIC TEMPERATURE INCREASE
STREAM TEMPERATURE (WINTER) HIGHER
LOGGING
UP-SLOPE CUTTING
STREAM-SIDE CUTTING - (CAREFUL & INTENSIVE TREATMENT)
SHORTER INCUBATION TIME - FRY EMERGE EARLIER
CHUM FRY - EARLIER TO SEA MARINE SURVIVAL LOWER
HIGHER STREAM TEMP. IN EARLY SPRING & SUMMER
TROUT FRY
COHO FRY
?
H
LONGER GROWTH PERIOD IN STREAM
MOVEMENT DOWNSTREAM
HIGHER GROWTH RATE IN SUMMER
P
P
TROUT LARGER (SEPT. 30)
COHO - LITTLE EFFECT
0 + FISH LARGER IN NOV.
TO ESTUARY -LARGER SIZE IN FALL
TO SEA -LOSS OF FRY
P
LARGER SIZE (NOV.) HIGHER OVER-WINTER SURVIVAL
D
MOVEMENT UPSTREAM
TO SEA IN OCT ?
EARLIER TO SEA -LOWER MARINE SURVIVAL
MORE SMOLTS AS 1+ FEWER AS 2+
LOWER % RETURN OF ADULTS
TOTAL SMOLT NUMBERS INITIALLY HIGHER, THEN DECLINING

Figure 4. A schematic diagram outlining the effects of logging activities on temperature processes and the effects of temperature changes on fish. The capital letter D, H, or P indicates the location of an important interaction with Debris, Hydrological or Production related processes. See text for explanation of line density differences and stippling.

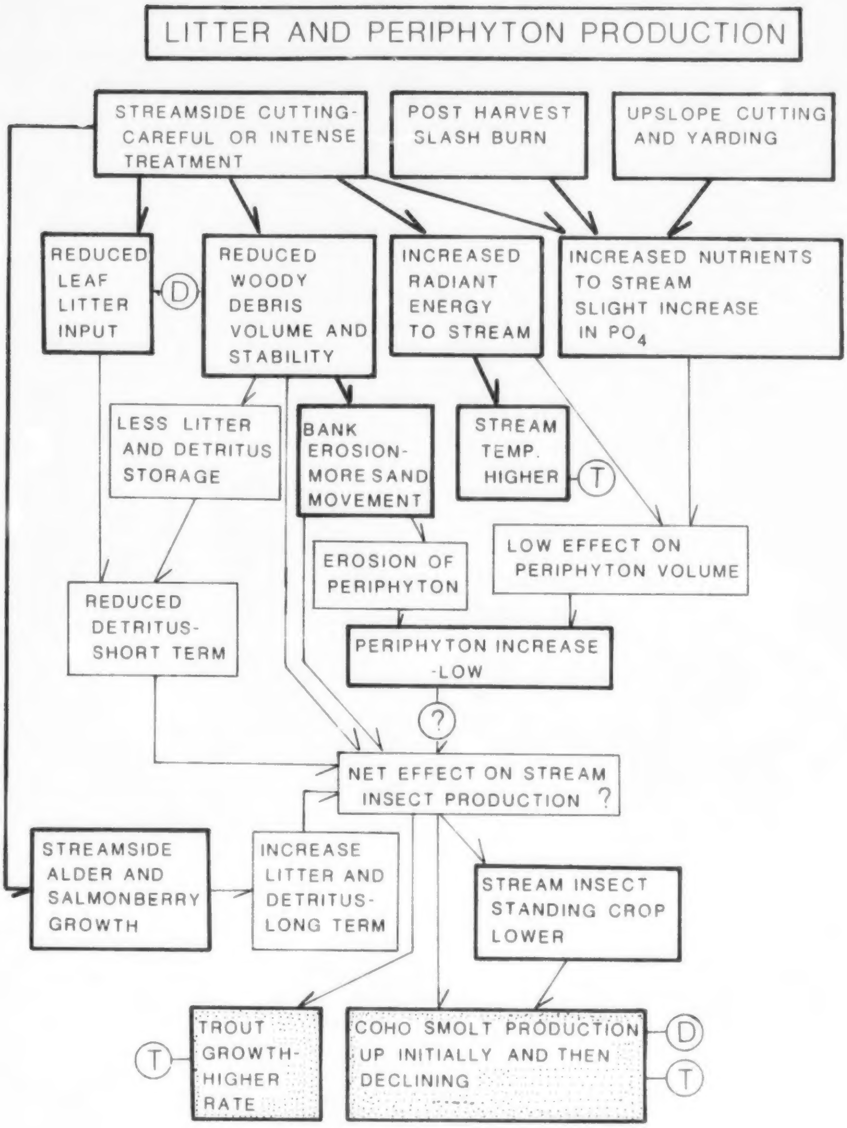
LITTER AND PERIPHYTON PRODUCTION
STREAMSIDE CUTTING-CAREFUL OR INTENSE TREATMENT
POST HARVEST SLASH BURN
UPSLOPE CUTTING AND YARDING
REDUCED LEAF LITTER INPUT
D
REDUCED WOODY DEBRIS VOLUME AND STABILITY
INCREASED RADIANT ENERGY TO STREAM
INCREASED NUTRIENTS TO STREAM SLIGHT INCREASE IN PO4
LESS LITTER AND DETRITUS STORAGE
BANK EROSION-MORE SAND MOVEMENT
STREAM TEMP. HIGHER
T
EROSION OF PERIPHYTON
LOW EFFECT ON PERIPHYTON VOLUME
REDUCED DETRITUS-SHORT TERM
PERIPHYTON INCREASE -LOW
?
NET EFFECT ON STREAM INSECT PRODUCTION ?
STREAMSIDE ALDER AND SALMONBERRY GROWTH
INCREASE LITTER AND DETRITUS-LONG TERM
STREAM INSECT STANDING CROP LOWER
T
TROUT GROWTH-HIGHER RATE
COHO SMOLT PRODUCTION UP INITIALLY AND THEN DECLINING
D
T

Figure 5. A schematic diagram outlining some relationships between logging activities and; litter input and periphyton accumulation in the Carnation Creek system. Some possible effects on macroinvertebrates and fish are indicated. The capital letter D, H, or T indicates the point of an important interaction with Debris, Hydrological, or Temperature related processes. See text for explanation of line density differences and stippling.

There are 5 points that should be noted in Figure 4 regarding the responses of stream temperature conditions to logging:

1. Changes in stream temperature occurred concurrent with streamside cutting.
2. Logging produced stream temperature changes which were evident during all periods of the year.
3. Temperature increases which occurred during the February to April period were smallest, but they had the most significant impacts on coho and chum salmon population processes.
4. Temperature changes early in the life of fish, e.g. coho, have effects on life history stages two to three years later.
5. In cool stream systems such as Carnation Creek, stream temperature increases of 2-3 C during summer may be beneficial for growth and production of coho salmon and trout. Some of the best opportunities for obtaining benefits for fish with forest cutting are those associated with improvement of temperature regimes.

There are 5 points in Figure 5 that should be noted regarding fish food production processes in Carnation Creek:

1. Leaf litter and periphyton both provide a basis for insect production.
2. Leaf litter input was reduced following logging but it is expected to rise again with streamside alder and salmonberry re-growth.
3. Primary production in the stream was limited by the amount of phosphorous present.
4. Phosphorous concentration in the stream did not increase during logging, but it began declining after logging had ceased.
5. Macroinvertebrate densities decreased after logging. This decrease in invertebrates probably occurred because of decreases in available detritus, and increases in the amount of sand moving along the stream bed.

INTERACTING EFFECTS OF PHYSICAL CHANGES

Temperature conditions, debris characteristics, gravel quality, stream hydrology and food production have interacting effects on fish production. Although I considered their impacts separately in schematic models (Figs. 2, 3, 4, 5) I will attempt to integrate their effects on fish production here. However, I do not use analyses or models, based on empirical information, which integrate the various effects of temperature, debris, gravel quality and food production changes on fish population characteristics. The integration of these effects is therefore subjective or inferential.

Steelhead Trout

Steelhead smolt production was lower after 1977 (Fig. 6) and although the length of pre-migrant steelhead increased the size of the smolts did not. Temperature increases had a positive effect on the sizes of 0+ and 1+ steelhead and cutthroat trout over the course of the study. Larger size, on September 30, in the latter part of the study was a composite effect of increased incubation temperatures (and hence longer growth period), warmer stream temperatures during the summer and lower densities of trout. This increase in lengths of steelhead during the autumn was not reflected in the size of the smolts in the following spring. I speculate that the larger and older fish may have had poorer growth, during winter, because of habitat change or else the largest fish had a lower survival rate. The habitat change presumed to have affected steelhead involved a decrease in the volume of large debris, and an increase in the degree to which it collected in single locations from 1600 m to 3000 m up from the stream mouth. This change reduced the amount and quality of winter habitat for steelhead parr over two years of age. Steelhead trout are less inclined than cutthroat to occupy small tributaries sloughs (Hartman and Gill 1968; Hartman and Brown 1987) or pond habitat (Cederholm and Scarlett 1981) so they may be more vulnerable than cutthroat to physical changes in the main- stem of the creek.

The trends in steelhead smolt production (Fig. 6) and adult numbers in Carnation Creek do not correspond to trends of steelhead abundance in the Keogh, Gold, or Somass rivers on Vancouver Island. Numbers of

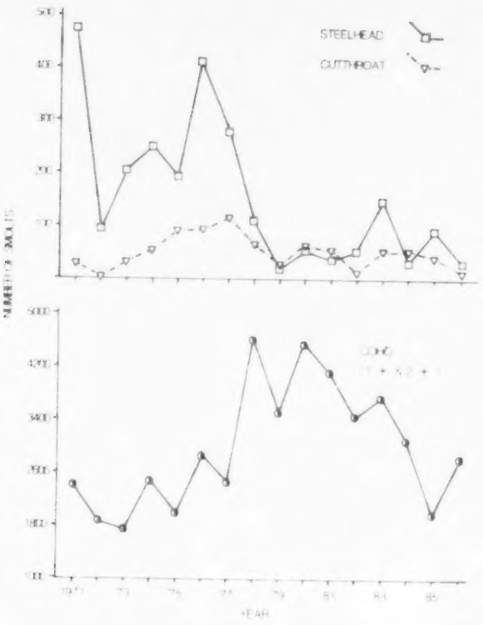

Figure 6. Numbers of steelhead and cutthroat trout and coho salmon smolts passing the main fish counting fence in Carnation Creek from 1971 to 1986.

wild steelhead in these three rivers, as indicated by angler catch per unit of effort, have been high since 1981 (Provincial government data). This suggests that steelhead population trends in Carnation Creek were not a reflection of coastwide patterns of abundance. The cause of the decline in steelhead numbers from 1977 to 1979, in Carnation Creek, should be sought within the system.

In summary, I suggest that the lengths of 0+ and 1+ steelhead were increased by temperature changes in a manner similar to that demonstrated for coho (Holtby 1988). Changes in debris characteristics and channel structure caused decreases in the survival and or growth, during winter, of large steelhead parr so that growth changes were not reflected in the mean size of smolts. It is also possible that relatively more steelhead migrated as 2+ smolts. The absence of any 3+ steelhead in the autumn population estimates after 1978 (Andersen 1983, 1984, 1985) supports this speculation.

Cutthroat Trout

Cutthroat trout smolt numbers varied from 4 to 117 from 1971 to 1986 (Fig. 6) and indicated neither negative nor positive effects of logging. The lengths of resident 0+ and 1+ cutthroat trout were positively correlated with thermal summation values based on their total growth period (Hartman and Scrivener, MS). The lengths of all 0+ and 1+ trout in the lower 3000 m of the stream were also positively correlated with thermal summation values during both their period of incubation and their period of summer growth. Longer length on Semptember 30 appears to be the effect of early emergence (longer growth period) and more rapid growth during summer. The effect of the logging and climate related increases in stream temperature, on cutthroat, are presumed to be positive. The changes in debris volume and distribution; and channel morphology had no apparent negative effect on cutthroat smolt numbers. Cutthroat trout parr were more inclined than steelhead to occupy small slough ponds (Cederholm and Scarlett 1981), or small tributaries (Hartman and Brown 1987), and to spawn in small tributaries <500 m in length (Hartman and Brown 1987). I speculate that this difference in the behaviour of the two trout species may have accounted for the maintenance of low but unchanged cutthroat smolt numbers, while the numbers of steelhead smolts declined (Fig. 6). Although the adult returns represent minimum numbers only (Hartman and Scrivener, MS), they too suggest that cutthroat populations may have been maintained longer into the logging period than those of steelhead.

In summary, there were positive effects of elevated stream temperature on cutthroat size. These may have been reflected in the high but variable mean lengths of smolts from 1980 to 1983. The capacity of cutthroat trout to occupy and spawn in small tributaries (Hartman and Brown, MS), may have permitted them to utilize main-stem habitat seasonally, or year around, and maintain their numbers, even though it became more difficult for steelhead to do so. Conclusions regarding survival were made difficult for cutthroat trout, because ocean going and stream resident populations could not be separated.

Coho Salmon

The changes in the numbers of coho smolts (Fig. 6) and spawners were caused by the interaction of temperature changes (positive and negative effects), and debris, channel morphology and gravel changes (primarily negative effects). Juvenile coho salmon had behaviour patterns (downstream movement during freshets and the use of off-channel habitat) that buffered the impacts of crowding and habitat loss. The climate and logging related temperature increase in the late winter and early spring was the initial and predominant positive influence on smolt production. The effect of stream temperature increase was to change growth patterns and survival rates of fry, not to alter numbers. The large number of smolts (Fig. 6), of which about 80% were 1+ in 1980, was not attributable to an increase in the number of adult coho.

Egg-to-fry survival of the age class of fry emerging in 1977 was about 24%. This was near the average for the pre-logging period. Densities of fry were high during summer (1977 and 1978) in the intensive treatment section of the stream. In 1979 and 1980 they were high in the careful treatment section of the stream (Scrivener and Andersen 1984). The intensive and careful treatment areas held relatively more fish, in the summers from 1977 to 1980 than before, because the fine debris temporarily created a more diversely structured habitat (Scrivener and Andersen 1984).

From 1977 onward the mean length of coho fry in late September, was 7 mm or more greater than it was from 1970 to 1976 (Scrivener and Andersen 1984). This increased size was caused primarily by the extension of the growing season (Holtby 1988). Fry size was correlated negatively with density (see density and fry size in 1980 in Scrivener and Andersen 1984). I conclude that the temporary improvement in structural diversity of habitat had a complementary effect to that of early emergence in the production, following logging,of the first three year-classes of larger fry. A freshet in late 1978 removed the small debris from the intensive treatment sections, and a second freshet in 1980 removed it from the careful treatment section. Following these the relative densities in these sections were lower (Scrivener and Andersen 1984). After the freshet in 1978 the stream channel began to erode (Toews and Moore 1982) and gravel quality began to change (Scrivener and Brownlee, In press; Hartman et al. 1987). Increased sand in the gravel and increased gravel scouring reduced egg-to-fry survival of coho from 1980 onward. Because of the changes in gravel characteristics the number of 0+ coho were lower in autumn population surveys in all years except 1980. Throughout the study coho fry moved seaward during freshets and they did so even during years when densities were low, (i.e. below those that the stream had accommodated in pre-logging years). After 1980, lower gravel quality and downstream movement of fry (density independent), during freshets, reduced the numbers of fry in the stream in late September. From 1981 onward the sizes of coho fry in late September continued to be large because of early emergence, longer growing season and lower densities (Holtby 1988).

The larger size of fry in the autumn increased over-winter survival and it caused a greater proportion of coho to go to sea as 1+ smolts. The reduced quality of winter rearing and egg incubation habitat were negated by the shorter time of residence in the stream. Before logging, total production consisted of 30% to 50% 2+ smolts. These two circumstances caused the increase in total smolt numbers between 1978 and 1983 (Fig. 6).

Physical changes in debris condition and channel structure had the potential to reduce overwinter survival of 0+ coho. However, many 0+ coho moved to small ponds and tributaries on the flood-plain during winter. Survival in this habitat was high and as much as 24% of the smolts produced came from flood-plain habitat. The behavior of moving to flood-plain habitat therefore buffered the impacts of winter habitat deterioration in the mainstem of the creek.

In summary, I suggest that:

1. The increased numbers of smolts, 1978 to 1980 were the result of relatively high egg-to-fry survival levels, of temporarily high summer carrying capacity from additions of small debris in 2 of the streamside treatments, and of a shorter average time of residence.

2. The sizes of the fry, in autumn, were larger because of earlier emergence from 1977 to 1985 that was caused by increased stream temperatures during egg incubation. After 1980, very low densities in summer also produced greater rates of growth.

3. Larger fry in autumn were more able to survive winter conditions in the main channel.

4. After 1978, the negative effects of declining quality of spawning gravel and of summer habitat partially offset the benefits of warmer temperature and fry production from high numbers of females which peaked in 1979. These in part caused coho smolt output to return to prelogging levels after 1984.

5. After 1978, the sizes of smolts emigrating to the ocean were smaller because large 2+ smolts became rarer.

6. The behavior of young coho, of moving into flood plain habitat during winter, resulted in high overwinter survival in such habitat on wet years and buffered the negative effects of main- stem habitat loss.

7. Warmer stream temperatures during late winter and early spring caused coho salmon to undergo parr-smolt transformation earlier in the year. The percent of adult return from smaller and earlier migrants was lower than it was from pre-logging smolts. This contributed to the trends of declining smolt numbers (Holtby 1988).

The complex of positive and negative changes and coho responses to them caused a disruption of the stable population trends of the pre-logging period. They caused the sharp increase and subsequent decline of coho smolt and adult numbers from 1978 to the present. Female coho numbers, egg-to-fry survival, numbers of fry, numbers of parr in the autumn population estimates and smolt numbers have all become more variable since 1977.

Chum Salmon

Changes in both channel condition and temperature regime had negative impacts on chum salmon production. Scrivener (1988b) has analyzed a series of variables that affect chum salmon survival from egg deposition to the return of the adults. Within the stream, changes in the stability of large woody debris and channel condition and the consequent decrease in gravel quality and stability reduced egg-to-fry survival. Increasing stream temperatures shortened the period of egg incubation. This produced earlier emergence and emigration of fry to the ocean, where they experienced lower survivals during early marine life (Scrivener 1988b). About 80% of the chum salmon return four years after the brood year (Andersen 1983). Adult numbers declined for five years from 1980 to 1984. In 1985 adult numbers were higher than in six out of nine escapement years before 1980. In 1986 they were lower than they were in any other year of the study (Hartman and Scrivener, MS). A long time series of data is required to demonstrate impacts, because conditions that affect chum salmon varied from year to year, and because the species has a longer (4 year) life cycle. Analysis by Scrivener (1988b) has shown that chum populations were affected by several environmental variables that have become less stable since logging was initiated. Only some of these variables were influenced by forest harvesting.

BENEFITS OF THE PROJECT

Multi-disciplinary 16-year research like that done in Carnation Creek has broad community benefits because basic understanding of processes can be directed and focussed to provide solutions to different types of logging related problems. It can be passed to and used by different interest sectors. The work done at Carnation Creek has already had application in a number of different educational processes, in drainage basin and stream restoration work and in fisheries forestry land use planning. In regard to the latter, the work has important potential application in the field of fisheries enhancement if or when such enhancement becomes planned as a part of forest harvest. Ultimately, 15 to 20 year studies in one drainage provide time series of sound, salmonid population data which are necessary for population modelling and management exercises. Very few such time series of data exist. Short term mission oriented research, also valuable, often focuses on one target and therefore has less potential for benefits across several sectors.

Education

With regard to the application of Carnation Creek to educational processes it is sufficient to say that over the course of the study more than a thousand industry and government land managers (forestry); and forestry students visited the site. Another 1200 to 1500 students and workshop participants have received lecture information on the project. The dissemination of research work through education and information is a route of application that has already been used for years. In this sense, we need not look for application, it has already been found.

Stream Restoration

With regard to the application of Carnation Creek results to stream enhancement and restoration, Hartman and Scrivener (1986) have presented enhancement strategies for main-stem sections, flood plain tributaries and estuary areas of small coastal streams. Completed experimental studies at Carnation Creek, which have determined specifically what winter habitat features coho respond to (Brown and McMahon 1988), will be applicable in the refinement of stream habitat restoration projects.

APPLICATION:

Land Use Planning

Very often when discussions arise about the "application" of Carnation Creek work to other systems the question is; how much can the work be extrapolated to other systems? If "application" implies that we should be able to apply the same treatments as those used in Carnation to a spectrum of other similar sized streams and predict, and obtain, identical responses to those recorded in Carnation Creek, then the work probably has little application. If "application" implies that research workers should be able to provide rigid recommendations about logging planning, then again, the work has little application.

I will offer two ideas about the application of our knowledge of drainage basin processes gained in this project:

1. Research information about processes is most useful when put in the hands of experienced managers and used in land use decision making in combination with the experience of the manager and with good site specific information. The bridge between process information from one drainage and the application in land use planning in many others is the experience and the ecological competence of the manager. Results from projects like the Carnation Creek Project, the Alsea River study, the Clearwater River work, and Hubbard Brook project are guides for planning not recipe books.

2. If we wish to consider how much or how often the Carnation Creek work may be extrapolated to other drainages it is necessary to have a system of stream basin classification in place. Drainage basins should be classified on the basis of a suite of features. If this is done, groups of streams will sort themselves, like species of animals or trees, into progressively more classes. The more similar the stream classes are to Carnation Creek the more similar will be their responses to comparable treatments. Maximizing the value of research results requires that we do other things (inventory and classification) as a part of management preparation.

Although there are many differences among British Columbia west coast streams there are some overriding conditions that dictate the need for emphasis on the management of certain features of the streams. Most of the streams on the coast are located in areas of steep topography and high rainfall. As a consequence, the streams are characterized by high hydrological energy and variability in discharge. Because they are cool, rapidly flushed and low in nutrients the biotic energy flow, among the stream communities is low. The regulators of fish population are directly physical: temperature, cover, winter flow conditions. Density of fish had some effect on coho size but it had little on that of trout. The trophic processes and competitive relationships do not, apparently, play the primary role in population processes. I would speculate however, that if the flow of biotic energy through the system was high, and hydrological energy low, population regulation and production processes would be regulated more by biotic processes than physical conditions. The hydrological energy of west coast streams is high, as a consequence, particular attention should be paid to management for:

1. Large woody debris.

2. Channel form.

3. Gravel budgets.

4. Temperature regimes.

Because the hydrological character of coastal streams is such that the changes, which freshets and land use might cause, may be long-lasting; there is need for special attention to the time frames over which responses may occur or changes may persist.

It is desirable to plan cutting and silvicultural activities so that the large woody debris in the channel remains stable and so that there is a future supply of such material. Grette (1985) has shown that the amount of large woody debris declines, after logging, for about 50 years before second growth trees begin to replace it.

It is desirable to plan cutting and silvicultural activities so that the normal changes in the bank structure of the stream are not accelerated. Bank structure and large debris determine the channel form. Channels with a variety of habitats, riffles, pools, undercut banks and large wood are most productive for fish. In Carnation Creek, in the careful and intensive treatment sections, the channel has become straighter, wider, and more shallow. It is not known whether the patterns of changes seen in the past 8 years will continue to occur. It is presumed that the channel will not begin to evolve toward a pre-logging configuration until stable, large woody debris begins to re-appear.

In undisturbed streams, gravel is moved from the upper reaches downstream. The movement and the retention of gravel along the stream depends on the interplay of freshets and large woody debris. In stream systems, in which the small steep slope tributaries are disturbed and the large woody debris is reduced or lost in the main channel, there is a risk that excess gravel may be transported out of the source areas and out of storage in the main channel; and flushed down through the system. There is a risk that after this initial period of gravel movement the stream may become gravel-poor with low gravel input and storage. It is also likely that sorting along the stream will result in coarse gravel or cobbles dominating the channel bottom in the steeper gradient sections and sand and fines doing the same in the lowest gradient sections. I stress that comments about gravel budgets are speculative. Volumes of gravel that have moved and are currently moving are poorly quantified. I suggest, however, that planning for the management of gravel supply and movement may be as important in the long run as planning for gravel quality. If there is a continuation of the Carnation Creek work one of the objectives should be to follow long-term changes in gravel dynamics.

Changes in stream temperature are a reflection of forest canopy cover over the stream and the slopes. It is anticipated that temperature of the stream will begin to decline as the canopy closes. Stream temperature increases were beneficial to trout and to coho during their first year in the stream. Streamside management activities in cool, outer coast drainages such as Carnation Creek, may well include changes that increase light on the stream surface and elevate stream temperature. The challenge for the managers, however, is to do this without causing changes in woody debris storage, channel form and gravel conditions.

In Carnation Creek we have identified the importance of flood-plain tributaries for fish production (Brown and McMahon 1988). Hartman and Brown (1988) have discussed the special need for management measures for such habitat. Three primary recommendations regarding fish habitat on alluvial flood-plains are:

1. Recognize its importance.
2. Identify it during winter before cutting and yarding plans are made.
3. Maintain fish access to, from, and through it.

Potential Responses in Different CoastalStreams

There are five sets of conditions in which it may be anticipated that stream systems, similar in size to Carnation Creek and within the same coastal zone, may not respond to 41% clear cutting as Carnation Creek has:

1. Different aspect.
2. Different elevation.
3. Absence of flood plain.
4. Presence of lakes.
5. Different gradient.

Streams with different aspect may not exhibit the same temperature changes as those recorded in Carnation Creek. North facing streams should be expected to exhibit smaller temperature increases during summer, following cutting. Streams which are south facing in wide shallow valleys should be expected to exhibit higher temperatures than were observed in Carnation Creek if a similar cutting program is employed in the basin.

Streams at higher elevation will be affected more by rain-on-snow events than streams within 500 m of sea level. In such streams winter freshets should be more extreme and stream temperatures lower during such freshets.

If streams without flood-plains are logged managers may not be faced with the problems of extensive lateral erosion of stream banks and consequent input of sand into spawning gravel. Extreme channel widening (2 to 3 fold increase in width) and decrease in depth may not be expected to occur. On the other hand the flood-plain may act as a fall-out area for sediment produced by upslope activities. Therefore, in the absence of flood-plains, sediment from yarding and post logging burning areas may enter the stream in higher concentrations. In stream basins without flood plains and the tributaries on them there will be fewer life history options for coho and cutthroat trout. Therefore, the impacts of structural changes in the main-stem of the creek, if they occur, will be more severe than was the case in Carnation Creek.

The presence of lakes will reduce the severity of freshets. They may also provide additional life history options for coho and trout; and permit the occurrence of other species, e.g. sockeye.

Progressively steeper gradients will produce situations in which fish have less access to upstream areas. The streambed should contain coarser substrate. They may result in different thermal responses to clear cutting than those which occur in low gradient streams.

Although I have listed these five conditions separately, it is clear that different streams may combine different features. Different combinations of features will result in different physical changes and fish population responses following logging. Because there is diversity among streams, even where there are important common hydrological features, I recommend that land managers establish matrices (see Fig. 1), that summarize activities and anticipated changes. By combining experience, site specific information and knowledge of processes resource managers may best anticipate the scale and nature of changes that will occur.

Management and Increased Population Instability

The results of work on chum and coho salmon indicate that populations may become much more unstable after logging. Managing unstable systems in which several variables may interact to generate high peaks of numbers or very low numbers, will be more difficult or risky than managing systems in which population parameters are less variable. It is as important therefore to understand the changes in population variability, which may occur following logging, as it is to be able to assess the impact on the average level of production of a population.

MANAGEMENT AND COMPLEXITY

Research people are repeatedly requested to provide short, simplified and easily applicable statements about forestry-fishery interactions. It is undesirable to make matters over-complicated. It is equally undesirable to oversimplify to the point of error or useless generalization. However stream ecosystems are diverse and complex. Intelligent management of such systems must at least recognize this complexity. The systems did not evolve with the anthropocentric goal of being easy for man to manage. The more resource managers understand the nature of processes and the causes of diversity in stream basin systems, the more flexible and the more appropriate will be their input into the planning process. I would therefore urge that we seek more understanding rather than more brevity and simplification.

Cooperation in the future to achieve the best combination of benefits from fishery and forestry resources will certainly necessitate more than blind statements either that logging is "good for the fish resource" or "bad for fish". It will require more understanding of processes in different systems. It will also require that land managers use as much of the present information as they can.

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Over the past 16 years scores of people have

contributed to the Carnation Creek project. I will not name these people, but those among us who find value in the project offer our sincere thanks to them.

REFERENCES

Andersen, B. C. 1983. Fish populations of Carnation Creek and other Barkley Sound streams 1970-1980. Can. Data Rep. Fish. Aquat. Sci. 415: 267 p.

Andersen, B. C. 1984. Fish populations of Carnation Creek and other Barkley Sound streams 1981-1982. Can. Data Rep. Fish. Aquat. Sci. 435: 63 p.

Andersen, B. C. 1985. Fish populations of Carnation Creek and other Barkley Sound streams 1983-1984. Can. Data Rep. Fish. Aquat. Sci. 553: 62 p.

Brown, T. G. and T. E. McMahon. 1988. Winter ecology of juvenile coho salmon in Carnation Creek: Summary of findings and management implications, p. 108-117. In: T.W. Chamberlin (ed.). Proceedings of the workshop — Applying 15 years of Carnation Creek Results. Pacific Biological Station, Nanaimo, B.C.

Cederholm, C. J. and W. J. Scarlett. 1981. Seasonal immigrations of juvenile salmonids into four small tributaries of the Clearwater River, Washington, 1977-1981. In: E. L. Brannon and E. O. Salo (eds.). Proceedings of the salmon and trout migratory behavior symposium. School of Fisheries, University of Washington, Seattle, WA 98195. 309 p.

Grette, G. 1985. The role of large organic debris in juvenile salmonid rearing habitat in small streams. M.S. Thesis, University of Washington, Seattle, WA 98195. 105 p.

Hartman, G. F. and C.A. Gill. 1968. Distribution of juvenile steelhead and cutthroat trout (*Salmo gairdneri* and *S. clarki clarki*) within streams in southwestern British Columbia. J. Fish. Res. Board Can. 25: 33-48.

Hartman, G. F. and J. C. Scrivener. 1986. Some strategy considerations for small stream restoration and enhancement with special emphasis on high rainfall area streams such as Carnation Creek, p. 69-84. In: J. H. Patterson (ed.). Proceedings of the habitat improvement workshop May 8-10, 1984, Whistler, B.C. Can. Tech. Rep. Fish. Aquat. Sci. 1483. 219 p.

Hartman, G. F. and T. G. Brown. 1987. The use of small, temporary, flood plain tributaries by juvenile salmonids in a west coast rain-forest drainage basin; Carnation Creek, British Columbia. Can. J. Fish. Aquat. Sci. 44: 262-270.

Hartman, G. F. and T. G. Brown. 1988. Forestry-fisheries considerations on coastal floodplains. The Forestry Chronicle (February) 1988: 47-51.

Hartman, G. F., J. C. Scrivener, L. B. Holtby, and L. Powell. 1987. Some effects of different streamside treatments on physical conditions and fish population processes in Carnation Creek, a coastal rain-forest stream in British Columbia, p. 330-372. In: E. O. Salo and T. W. Cundy (eds.). Streamside management: Forestry and fishery interactions. College of Forest Resources, AR-10, University of Washington, Seattle, WA. 471 p.

Hartman, G. F. and J. C. Scrivener. Forest harvest and processes of change within a coastal stream ecosystem, Carnation Creek, British Columbia. MS in prep, 281 p.

Holtby, L. B. 1988. Effects of logging on stream temperatures in Carnation Creek, British Columbia, and associated impacts on the coho salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 45(3): 502-515.

Scrivener, J. C. 1988a. The Carnation Creek Experimental Watershed Project: a description and history from 1970 to 1986, p. 1-10. In: T.W. Chamberlin (ed.). Proceedings of the workshop — Applying 15 years of Carnation Creek Results. Pacific Biological Station, Nanaimo, B.C.

Scrivener, J. C. 1988b. A summary of the population responses of chum salmon to logging in Carnation Creek, British Columbia, between 1970 and 1986, p. 150-158. In: T.W. Chamberlin (ed.). Proceedings of the workshop — Applying 15 years of Carnation Creek Results. Pacific Biological Station, Nanaimo, B.C.

Scrivener, J. C. and B. C. Andersen. 1984. Logging impact and some mechanisms that determine the size of spring and summer populations of coho salmon fry (*Oncorhynchus kisutch*) in Carnation Creek, British Columbia. Can. J. Fish. Aquat. Sci. 41: 1097-1105.

Scrivener, J. C. and M. C. Brownlee. In press. Effects of forest harvesting on spawning gravel quality, and on incubation survival of chum (*Oncorhynchus keta*) and coho salmon (*O. kisutch*) in Carnation Creek, British Columbia. Submitted to Can. J. Fish. Aquat. Sci.

Toews, D. A. and M. K. Moore. 1982. The effects of three streamside logging treatments on organic debris and channel morphology in Carnation Creek, p. 129-153. In: G. F. Hartman (ed.). Proceedings of the Carnation Creek workshop, a 10 year review. Pacific Biological Station, Nanaimo, British Columbia. 404 p.

PANEL DISCUSSION
SESSION 6: INTEGRATION

The moderator of this session is Grant Ainscough, who is chief forester and vice president of MacMillan Bloedel.

Grant has been a chief forester and a professional forester, but probably more important without exception he is the most senior forest industry person in British Columbia that has consistently right from the start been a supporter of the Carnation Creek project and still is, and you will soon hear about that from him.

INTRODUCTION TO INTEGRATION PANEL:

MR. AINSCOUGH: Before I get serious , has anybody looked at this lectern? Some guy built that thing, then he cut it on a 45 degree angle so he could he get two sheets out of that. It didn't matter whether your papers were going to slide off or not, but he didn't build it for looks or efficiently, he built it cheap.

Maybe that does lead into what I'd like to say in my introductory remarks, because what we're dealing with we can't really do on the cheap.

I feel very privileged to moderate this mystery panel. Looking at the title that we were given, Comparisons and Applications, I thought that was a little bit abstract, and thinking back to the ten year results' meeting, a lot of people left pretty frustrated. They had some preliminary data, they weren't too sure how hardened off it was, weren't too sure just how much they could rely on it, but they felt like they had been given something here and that they should go away and do something with it. And I guess it created a lot more anxiety than it did comfort in the managers of the resources. I think it was of some considerable more benefit to the researchers who were exchanging experience and challenging one another's results.

So anyway, I changed the title. "Where Do We Go From Here?", and I think with the 15-year results, we've got a little bit more to take away than it hardened off on, but I'd like to focus that a little bit. For the rest of the morning - and the speakers have been chosen deliberately with this in mind - let's focus on developing a sense of direction.

I'd like to break it into two parts: firstly in regard to the Carnation Creek project, but secondly to translate what we know or what we think we know into an action program of habitat management.

Now, this mystery panel will soon be revealed to you. Before that I'd like to steal a little bit of time as the moderator to espouse some of my own biases.

Dave Narver and I were talking a little bit earlier this morning about the origin of the Carnation Creek project, which was really the result of a conversation on the ferry, an expression of a bit of frustration on Dave's part at what he was dealing with in the Nanaimo River project where he had some very interesting results, but he really didn't feel confident to harden off on those.

So I introduced him to Frank Garrison. He said, I don't know whether a logger will talk to me or not, but Frank, anyway, was the guy who listened to what Dave needed by way of a watershed and a commitment and basically found Carnation Creek.

It was a pretty simple concept at first, but it didn't take long as we got into it to get complicated. Somebody mentioned yesterday that this was really an impact study. Well, it started that way, but it didn't take long to get much more complicated than that.

We set up a working committee and got as many agencies involved as we could, but it was very clear from the beginning of that discussion, and I guess J. "Carnation" Scrivener can testify to this, that it was hard to get the commitments and to get people, different agencies and so on to realize that they had a long range commitment in this.

So after a little feedback, Dave and I had a pretty good discussion about it, and Radway Allen was persuaded to use his position to establish a coordinating committee, and that brought the honchos in from the different agencies, and they had to sit there and eyeball one another and commit themselves to doing certain things.

We had annual panics over budgets, calling one another. I had to go and see Jack Davis once when he was Minister of Fisheries and plead with him to recognize that were some new things coming that had to be budgeted and had to be sustained. Governments are never very good at making long term commitments. Said they didn't have the authority and so on.

Well, our company has prepared a plan to complete the logging in the next ten years, which I believe is compatible with the objectives of the project, and we're prepared to continue to support it in other ways.

We're asking for a long term commitment by other agencies on the basic monitoring and analysis that must be continued, and to a guarantee that no activities will be permitted which are not completely compatible with the original objectives.

Carnation Creek must not become a playground. We view this watershed as a living laboratory which will yield invaluable data in perpetuity. It must be protected from mental aberrations such as the so called intensive logging which caused unknown impacts downstream.

And there's no doubt that monitoring can and should be scaled down, and that some resources should be committed to other research watersheds that are representative of other conditions, and I wouldn't be the person to judge the extent of that need.

However, I would repeat that it's unthinkable, would be irresponsible to suggest that this unique and valuable project be interrupted, let alone wound down, or that it be shortened in any way that might imperil the quality of the data, if it was done on a shoestring in any sense.

We depend very, very heavily on the five year before logging monitoring. We did not or could not afford to get a parallel watershed for a full control. We did not and really didn't have the resources and maybe not the awareness to put the full effort into the estuarian studies at the same time. Hindsight from experience would maybe help us to design other research watershed projects.

I'd like to go on then to a second question, and I'll be brief, and I'm going to run the risk of being misunderstood for that reason, but that is not uncommon.

First, there is an organization review going on right now in the Ministry of Forests and Lands and throughout the provincial government, and there has been a suggestion that the Fish and Wildlife branch should be transferred to the Ministry of Forests and Lands, where it could be integrated and maybe better funded.

From my own inclination or intuition I think the results of that would be positive, but I don't know, and I suggest that the people who do better think it over very carefully. Get your position on a piece of paper in one paragraph and mail it to the Premier. Don't wait to phone in to his radio show. Mail it to him right now. Tell him what you think, because a decision is going to be made, and the more informed people who register their position on it, the better the decision will be.

Okay, where do we go from here? First, by all means let's establish more research watersheds, but more to the point, let's get on with habitat management. To a forest land manager, that means getting the best available facts on the resource and then manipulating it to realize its best potential usually with some economics driving that. But it's now time, I believe, for habitat managers to manage.

We, operating in the uplands, can, and will cooperate, and we can and do adjust our operating plans to minimize the impact on the fishery, but we're not in the business of managing fishery habitat, nor are we qualified to manipulate that habitat.

It may be presumptuous for a forester to tell another resource manager how to do his job, but here goes. Everybody does it. They do it to me. I think as a first priority there really are three steps.

First, let's get busy and complete and publish the stream inventory designed for managers. It won't be perfect, but it can be upgraded progressively as we work with it.

Second, let's define the optimum and minimum habitat requirements by species as best you can from current knowledge, then let's pick some promising streams and assess them against their potential, and then make some specific project plans to correct either nature's limitations or past damage, and then let's get on and do them.

I'm not belittling the approach through public education and involvement in the salmonid enhancement program. I was a charter member of the Salmon Enhancement Task Group, and I know the value of the program that's being done, but I don't think we can rely as a first line on a bunch of school kids putting incubation boxes in streams. We've got to get a budget and a program and a habitat manager has got to be able to go out there and manage, and that means manipulating the resource.

And then finally, I think we come to the point where, based on operating experience, those habitat managers can begin to direct research biologists into the most needed and fruitful areas to research. I think that's where there will be a great deal of clarification and satisfaction in the research biologist's career.

But I'd like to close by quoting from Tom Siddon's comments to the Salmonid Enhancement Task Group last November, which was entitled "The Road Ahead At A Ten Year Perspective". These are a few of his comments out of context:

"We also need architects and blueprints, habitat managers. We have for the first time a formally enunciated policy for the management and expansion of fish habitat in Canada. Policy declarations are the green light for action. They legitimize goals."

And I think there's the clear welcome mat to go back and say you're telling us to manage. Okay, these are the resources we need. This is the mandate we need, and we can assure you that we have the cooperative support of the forest industry who will be the principal interactor in this. I think that's a safe guarantee.

Those are out of context, but it sure is an invitation. In fact, I would be stronger, it's a clear challenge for resource managers to use the knowledge we have now and get on with the job.

Now, our first panel speaker is Vince Poulin, and Vince graduated from Utah State in 1970 with a B.Sc. in Fisheries. He worked extensively in Alaska and Western Canada -- Western Canadian Arctic and on arctic grayling and char from '72 to '77. He came to B.C. in '74. He didn't start to work on salmon until '78.

He had major projects involved with the Fraser River Training Works on salmonid distribution and studied the effects of pulp mill effluent on juvenile chum migration up in the Neroutses Inlet, and he headed up the Forestry Fisheries Interaction Program in the Queen Charlotte Islands, a program which concluded its five year initial stage. And coincidentally, Vince is on contract as our new coordinator for the Carnation Creek project, so I think it's quite appropriate that he lead off for the panel.

VINCE POULIN:
FISH/FORESTRY INTERACTION PROGRAM

Ladies and gentlemen. "Where Do We Go From Here?". With the summation of the Fishery/Forestry Interaction Program work in October 1986, representing five years of study on the Queen Charlotte Islands and now fifteen years of the Carnation Creek fish project, we've come a long way in the better understanding of the effects of logging on fish and fish habitat. Despite the complexity that Gordon talked about, there are a series of common denominators that tie the results of the FFIP and Carnation Creek together. These are the physical forces that work on stream channels and the changes that these forces evoke in streams following logging.

I think that we should be able to go away from this workshop as Grant said, and get on with the job. I think it is going to require additional field work, additional studies, but most of all, as Gordon said, getting practitioners working directly with the forestry industry to implement the information that's been presented here and at the FFIP workshop.

Lets first look at FFIP and then Carnation Creek. That day that Eugene Hetherington photographed me trying to come up with some thought provoking questions at Carnation Creek, I followed Gordon further up the creek to a point where we were standing on a debris jam, and Gordon said, "I think Vince

Poulin ought to feel at home now." What we were doing was standing on the toe of a 1984 debris torrent, and as Gordon guessed, I indeed felt at "home".

We could have been on any number of Queen Charlotte streams that had been affected by mass wasting. Thus, from Day 1 I began thinking about comparisons between the two studies and the applicability of F.F.I.P. results to Carnation Creek.

Over the past five years some fifteen project leaders and myself have been actively involved on the Queen Charlottes dealing with another hot bed of issues. Carnation Creek dealt with streamside logging treatments. On the Queen Charlottes we focused on another major problem — steep slope logging and the effects of landslides on fish habitat and also how to log steep slopes without major impacts on downstream resources?

The fish/forestry program that was started in 1981 and differed from the Carnation Creek watershed in that it was designed as a synoptic survey. In other words we looked at a large number of stream systems over a much shorter time period. Thus, we had the opportunity of examining a large number of systems with varying logging and mass wasting histories from which to draw comparisons about logging impacts.

The two studies are complimentary. The difference between the two is that scientists at Carnation Creek worked to explain how a system functions, while those of us involved in FFIP research looked at major changes attributed to logging. This was done by comparing stream systems exhibiting varying degrees of impacts ranging from none to worse case.

The greatest distinction, between the two projects was the opportunity in F.F.I.P. to look at a range of stream systems and to carry out a host of less intense studies that were followed by more detailed work on a smaller number of streams.

Results of the FFIP project are not unlike what was discovered at Carnation Creek and thus, suggest there are a number of common denominators that similarily describe the the effects of logging on fish. On the Charlottes there are some 350 streams. Ninety-five percent or so are first and second order streams. There are about 100 small streams draining into Barkley Sound of similar size to Carnation Creek. All are in high rainfall areas and most have shallow soils. There are similarities in many of the areas you are working in.

Now let's look quickly at some of the results from the two projects that are common to both. First of all, F.F.I.P. was dealing with landslides. Our main thrust was trying to document the number of landslides that occur from coastal logging and their impacts on fish habitat. We found that logging on the Charlottes does significantly accelerate landslides. We learned that landslides, particularly in the form of debris slides and debris flows that occur in gully areas, have the potential for entering stream channels and the greatest impact on fish and fish habitat.

Six failures have been recorded in Carnation Creek since logging. Out of the six, one was a major debris torrent. Carnation Creek is a relatively stable watershed, but only recently logging has moved on to steeper lands. The slope processes that occurred in Carnation Creek are not unlike those that take place on the Charlottes.

Once a debris torrent or slide enters a stream channel, it has an enormous power to alter that stream. Major changes include a reduction in large woody debris; a reduction in the stability of the channel; a reduction in the area of pool; shallower pool depths; we get increases in riffles - and width increases. The net effect is to reduce the quality and quantity of fish habitat, particularly fish overwinter habitat.

With the massive amounts of material that are introduced in a system by slides the amount of fine material also increases. The concentrations are not as large as what Jeff Cederholm and others have seen in Oregon and Washington, but are sufficient to have a significant effect on potential egg to fry survival.

Lets look at Carnation Creek. Aside from temperature, I feel the principal effects that were reported at this workshop are the effects of streamside treatments on bank destabilization and channel erosion. These changes lead to L.O.D. instability, which in turn resulted in major changes in channel geomorphology. Riffle area increased and pool depths were reduced. These are the same changes that we've reported on the Charlottes following mass wasting.

The common factor here is the hydraulic forces that shape channels. Since they are the same, the results are similar. Regardless of where you are on the coast, once you initiate these processes in a stream, you can expect a similar response. They are the hydraulic conditions that Gordon talked about and are responsible for the most significant alterations that occur.

These are the common denominators that enable extrapolation of Carnation Creek results to other areas. Gross changes in channel geomorphology resulting from the intensive treatments are similar to the effects we observed on the Queen Charlotte Islands from mass wasting. On the other hand, if temperature impacts in Carnation Creek could have been mitigated, we may have seen some of the most dramatic net-positive responses in coho populations perhaps recorded.

It is important to remember that Carnation Creek is examining streamside logging treatments from an era we have hopefully long since left behind. With today's management practices and conservative attitudes toward maintaining channel integrity, we have the opportunity to prevent the channel responses we've observed in Carnation Creek from logging.

Our biggest concern now comes from the fact that much of the remaining harvestable timber is found on steep slopes. Mass soil erosion can, in fact, prevent us from deriving the benefits of good streamside management.

Carnation Creek has enabled people to better understand how to manage stream channels and the necessity of buffer strips. So where do we go from here? The next step is working with the logging companies - getting out in the field and doing operational field trials that will not only further biologists' knowledge of how stream systems work, but to communicate this knowledge to loggers.

One final comment — I think the time is ripe for biologists and loggers to work together. At the Queen Charlotte Workshop in October, we had a very positive response from industry. Because there is opportunity to do a better job they were not taken back by the impacts reported concerning mass wasting. There is also an opportunity with further research to involve the forest companies in joint demonstrations and operational field trials and a more communicative information transfer.

MR. AINSCOUGH: Thanks very much, Vince.

I should say a little more about our mystery panel, I guess. Jeff Cederholm, who was Mr. Clearwater Creek, will be our next speaker. He will be followed by Peter Bisson from Weyerhaeuser and then by Jim Sedell, who we know has one of the most interesting collections of slides of anybody that I know.

So carrying on, Jeff Cederholm, who most of you in the fisheries area know, is with the Washington Department of Natural Resources as a fisheries scientist, guru, mentor, trainer and also has had coincidentally fifteen years on the Clearwater River Basin study.

His real interest or mandate is in putting research findings to work and in fostering a cooperative approach to timber and fisheries management. So I think it's entirely appropriate that Jeff come and tell us how he is doing it.

DR. CEDERHOLM,
WASHINGTON DEPARTMENT OF NATURAL RESOURCES

Thank you very much. I appreciate the introduction.

Well, I am very honoured and I appreciate a chance again to come to your workshop. I was at the ten year workshop, and I was at Parksville, and I appreciate your reaching across the border and getting us involved in your business, and you've certainly contributed immensely to our knowledge of this issue. And Dave Narver has always been so friendly and Gerry Taylor and others to get us involved and keep us informed on things over the years.

In 1974 we came up and saw Carnation Creek before it was logged and took a number of slides and looked at some of the other rivers in that area. And I went through my files and I brought my slides with me, and I gave them to Charlie to put into his bank of information.

But I just wanted to say that I appreciate it immensely, and it's been invaluable to us south of the border in formulating our studies over the years. We've used a lot of the information that have been gathered in the earlier years and on through the study. We couldn't have done it without you, believe me.

And I'd like to acknowledge Gordon Hartman myself. He's a real gentleman and a real pro. Let me tell you, he's been a real friend to me over the years since he has become associated with the Carnation Creek study and compared notes over the phone, and we've gone to a number of meetings, whether it be here in the lower B.C. or up in the Charlottes, and I tell you, I sure gleaned a lot of helpful information from him.

The publications and the information that's come available since Gordon took over has been absolutely monumental, and the paper that he described this morning was a difficult and complex issue for him to cover in the time given, but I sure encourage you all to really study it, because there's a lot there that if you really sit down and work at it, give yourselves some time underneath a nice lamp in the evening, a cup of coffee or whatever you care to drink, and just work your way through it, and there's an awful lot there.

Vince covered a lot of really important points in comparing the processes of the physical changes that have occurred and how that relates to what we really need to think about doing in our management. So I'm not going to belabor those points any longer.

There's a couple things I'd like to say about the Carnation Creek study. I think that there's a few things that we really need to give a lot of thought to in the future with the Carnation Creek study, and that has to do with the gravel changes. Not so much the sediment and silts, although that's important, and I think Vince mentioned it and Gordon mentioned it, it's the changes in the channel form that are occurring.

I've seen a lot of streams - I know you have too - over the years and when you look at the logging streams, you see the same scenario: the bedload changes that are occurring, the increase in the bed and the lowering of the water capacity to the channels, the shallowing and the bank erosion, the widening.

We see this a lot down in Washington, and I've seen it in other areas. And I think the channel form and processes really need to be emphasized in the future, because I think a lot of the explanations of the changes are going to be coming from that area and particularly as you get into the steeper logging.

And related to that, you have several main things; one would be the summertime dewatering, which Dave Bustard pointed out the day before yesterday. I don't know how many of us caught that, but it was a really, extremely important point.

Another one that Dave reminded me of was the spawning eggs. In the winter low flows, the eggs are perched up in that gravel that has come down and been deposited, and as the water drops in the winter time, some eggs could become dewatered within the gravel unknown to us, not able to see them.

Another thing is the channel shifting and scouring of salmon nests.

Okay, one interesting little exercise you might consider pursuing, I don't know who exactly would do this, but maybe Doug Morrison and people with his expertise, to look at how you would -- in knowing what you know today - you might consider sitting back and seeing just what it would have cost and how you might approach logging Carnation Creek again. If it was in the natural state, what kind of logging plan, roading plan, would you set out to maximize the positives that Gordon has pointed out and minimize the negatives, and what would it cost really to do a careful job?

I would like to continue to mention that I am very hopeful that the Carnation Creek study will continue. We have in other areas of the northwest had studies, and Alaska had a study back in the fifties, and Oregon has been mentioned, the Alsea watershed study. Then in Washington the studies I've been involved in. We have all done our part and learned from each other, and the Carnation Creek study has built on top of our studies in contributing to the success of ours, and I hope that we've contributed in some way to their success.

But ultimately it's what we have going right now in Carnation Creek, and there's never been such a fine piece of work, in my opinion, in terms of monitoring the long term. So I really hope that we can continue.

And finally, I just want to say that I think that in B.C. the whole approach to land management is much different than what I'm used to in the state of Washington. In the State of Washington, we have the State of Washington Forestry Department that has a set of forest practices, rules and regulations, which we administer on our state lands and on private lands. We are responsible to see that all these management implications are considered when we lay our timber sales, and we are also responsible to see that these guidelines are updated when newly significant information becomes available.

And right now in the State of Washington we have just completed a whole revamping of our forest practices, rules and regulations, through an integrated process of involvement between the land owners; the private industry, the state [illegible]; the other interests, the environmental groups which are an extremely important lobby in this State of Washington to make sure that lands are managed properly, and they have a tremendous influence in the State of Washington; and then an influence that is as great or even greater is the tribal influence. They have a tremendous hammer: the courts.

There's a lot of money that has been spent in our state in courts, trials and going to court to sue land owners for poor practices, because we have a lot of rules on the books that we just haven't been following, and the people who are enlightened can step in and take you to court on that and make you really pay through the nose. That's the way it is in the State of Washington, and we're continually aware of that.

In British Columbia, I sense that the regulatory side is not different. I see the timber industry is extremely -- I'm going to say powerful and almost even over the interest of the public. This is a personal opinion I've gained from my observations, and I think there's a place here that the timber industry has a responsibility, I think, to do a little bit more in going a step further in managing lands in this area.

That's just my own personal opinion. I could be off base, and please correct me if I'm wrong, but I see almost a fear of the timber industry because it has a tremendous impact on the economics up here.

But I think in our state we have found that -- we were afraid to do too much, spend too much effort on some of the things that were coming up in research. We were afraid it was going to cost us an awful lot of money to protect streams, and there were the worst case scenarios running around.

But we found when we started to really look at what it was costing us, when we went down and managed effectively in these repairing years, it really wasn't costing us as much as we always thought it was going to. Some things Jack Dryburg was saying in his presentation, some key points he hit on and how to manage streamside areas for short term and long term recruitment of large organic debris and protection of streambanks, he had some really key factors there that we've used and we have found that it's not costing as much as we always thought it was going to. The savings we made in keeping out of court and good P.R. with the public have paid many fold over the years, and we hope that it will continue in the future.

MR. AINSCOUGH: Jeff, thank you. I can't think of anybody that's afraid of me, not even my dog.

I suppose, Jeff, that point that's made is well worth looking at. I think fear is one of the terrible problems that we have in anything we do. You are afraid to go and [illegible] because you're afraid he might [illegible] think you're crazy. You're afraid to try something because it might go wrong.

A [illegible] coming out of the recession over the last few years is afraid to ask for some money to get his [illegible] back on track. We're afraid of the Fisheries Act so you do things -- you know, if you're going to [illegible] the theme [illegible] coming up, the next speaker, I think that's the first thing that we've got to get rid of.

If you're going to [illegible] -- I don't want to steal his thunder, but if you're going to have the kind of relationships that he terms co-management, then that's the first thing we've got to get rid of. So thank you for bringing it up.

Our next speaker is Peter Bisson. He took his Masters and his Ph.D. in fisheries biology from Oregon State University. He's had twelve years with Weyerhaeuser now as aquatic biologist. He's been mostly involved in research in forest management and fish population and streams.

His specific interests include habitat classification, salmon and trout life histories, and limiting factors. His primary research goal is to learn how private industry can do a better job of co-managing timber and fisheries' resources.

The people will be very interested to hear what you have to say.

DR. BISSON,
WEYERHAEUSER COMPANY

Thank you, Grant.

In his closing remarks today, Gordon touched on the need for effective communication. Several times over the past couple of days fishery biologists have stood before you and said, "I have examined the data, and we need more streamside protection." Likewise several times over the last couple days foresters have stood before you and said, "I have seen the data, and I don't think much is happening in Carnation Creek to the fishery resource."

I would suggest that something is still missing from the process of communicating the results of transferring any information that's found at Carnation Creek to the operational forester.

As a representative of private industry, we're keenly aware of a need for that process and that dialogue to continue. In the United States, the Carnation Creek study has been very important to us. It's been important for a couple reasons: one, and for the obvious reason, is that it consists of a large number of very well done, very well integrated process oriented studies.

There is another reason too, and that is this study was done in Canada. It was done across the border. Private industry from the United States has not had a chance to mess it up. Government agencies from the United States have not had a chance to mess it up. We do not own the study, and for that reason it's been very valuable to us. As well as its association with the Pacific Biological Station, we in the United States take that very seriously. We don't have that.

For that reason, I think it would be important for at least one of the panelists this morning to look at the specific technical conclusions that have emerged from the Carnation Creek study in the context of three questions. All of the questions have to do with applicability of the study to other areas, and again this is very important to us because we're in another area: we're across the border.

Those questions are: What are the findings that have broad generality? What are the findings that may not be safely extrapolated to other areas? Finally, What are the findings where the applicability to other areas simply is not known? And I'd like to take a shot at them.

There probably are a number of things on here that are quite debatable, particularly among the biologists, and I imagine I'll probably get into a lot of trouble with my biologist colleagues for saying some of these things. First, I'd like to start with things that I feel can be safely extrapolated to other watersheds, and I'm not going to begin with the physical system, I'm going to begin with the biological one.

To me the most interesting and critically important work that has emerged from Carnation Creek has been an improvement in our knowledge in the life history patterns and the behavioral ecology of salmonids. That to me is the trump card of the very fine biological work that has been done at the stream, and I think that as we follow the lead of a number of the Carnation Creek studies in other areas, we're seeing that the same life histories and the same behavioral patterns in coastal watersheds are repeated all the way from northern California to southeast Alaska. I give as an example the excellent and still to this day definitive work on winter habitat that was done in 1970 by Bustard and Narver.

The second finding from the Carnation Creek study that I feel is widely applicable is the change in the distribution in abundance of debris that has accompanied streamside management. Those findings to the destabilization of pieces, the increased bunching, the overall reduction, the short term increase in small stuff, those are turning up with regularity in coastal watersheds throughout the northwest.

The third finding that I think is widely applicable is very much linked to the presence of debris as the other speakers have said, and that is the changes in channel morphology, the restructuring of large debris in the creek along with an increase in the sediment load.

I think the increase in water yield from smaller watersheds that were studied are also widely applicable. They've been documented in Oregon, Washington, and Alaska.

Finally, I suggest that the importance of the flood plain, even in the small watershed like Carnation Creek, is a finding that we can safely extrapolate to other areas.

Now comes the dangerous part, the things that I think may not be safely extrapolated to other perhaps geologically and geographically diverse watersheds. My first item is the specific beneficial effects of increased temperature on fish production.

I am familiar with some areas where the increase in temperature may exact a metabolic cost from the fish that far outweigh whatever benefits it may have in terms of increased length of growing season or possible secondary effects through the food chain.

Carnation Creek is a cool watershed. Many watersheds in the northwest that are managed for timber production are not as cool and contain a great deal more diversity of fish species than Carnation Creek. And some work in Washington, for example, suggests that we may see a final replacement of one species by another that occurs concurrent with increases in temperature.

A second finding that may not be widely extrapolated is the finding that phosphorus was limiting to periphyton production in Carnation Creek. In western Oregon and Washington where most of the watersheds are dominated either by volcanic or sedimentary rocks, the nitrogen to phosphorus ratio suggests that in many cases nitrogen and not phosphorus is the primary limiting nutrient.

Third, the decrease in aquatic invertebrate densities that have been found in Carnation Creek I think have not been found in some studies in other areas following logging, and that includes some work in southeast Alaska and Washington, Oregon, and Utah.

Carnation Creek is far from over.

The second is destabilization of fish populations. It's clear from the curves that have been shown to us over the last few days that the populations have become less stable. We don't know how long they are going to continue to be less stable.

I was pleased to see the modeling effort Blair had tried, and I think that's a useful framework for us to begin to think about such problems as population instability in a management context.

Finally, I'm not sure if we're still to the point yet where we know to what extent we can extrapolate the results of the Carnation Creek studies to larger basins. Can these findings be safely extrapolated to the Stamp? Can they be safely extrapolated to the Cowichan? Can they can be safely extrapolated to the Fraser, and in what way?

Charlie Scrivener has emphasized that Carnation Creek is not a long term study. He's right. Again from the European research, I'd like to quote - and that's a quote from memory, but a recent review of J.M. Elliot of an eighteen year study of anadromous brown trout and Black Brow Beck in the British Isles. It's Finally, and this was one of the real biggies, I think, in Gordon's paper this morning; the regulation of the fish populations in Carnation Creek has been primarily governed and regulated by the physical habitat. I think this is something that we may not yet be able to safely apply across the board in the northwest. There may be more stable stream ecosystems in the northwest where regulation of smolt yield may be more strongly influenced by such biological processes as competition, gradation, and food production, and Gordon said that very well in his talk.

I'd like to also give an example that's recently come out from Europe from work on brown trout in rivers in Poland where a scientist found that primary mode of regulation in headwater streams was abiotic physical processes lower in the main river. The primary mode of population regulation were biological processes of gradation and competition, and he termed this abiotic/biotic regulatory continuum. I don't know if that works in the northwest, but it's an interesting hypothesis, and it's worth looking at.

Finally, I'd like to address things that we definitely don't know, in my view, whether or not we can safely extrapolate. One is the recovery rate of the habitat. And, in fact, the story on habitat recovery in probably one of the best long term studies in Europe. His observation was that the major shortcoming of the study was that data were available for only eighteen years, and he wasn't kidding.

And I don't think these guys are either, and I hope that I won't be too far out of bounds in adding the voice of American private industry to those of many others who feel that this study should continue, and it should continue to be well funded and well thought out and well conducted.

Thank you.

MR. AINSCOUGH: Pete, thanks very much. I know that he brings a perspective to this, and it is very encouraging to hear his comments.

Our next panelist has been heard from before as an entertainer, I suppose, as much as spear chucker, and sometimes biologist.

Jim Sedell is a graduate from Willamette University in philosophy and political science, would you believe. And from that base went on to take a doctorate in environmental biology from the university in a city where even the football players wear black. Perfect place to learn about environmental matters, in Pittsburgh, Pennsylvania.

He was the assistant professor in the department of fisheries and wildlife at O.S.U. for seven years. He was secretary manager of the forest/fisheries research group in the Weyerhaeuser company for two and a half years, and then research ecologist with the U.S. Forest Service at Corvallis for the last seven years.

I'm not sure whether he went from a big outfit to a bigger one or to a smaller one, but anyway he's been actively involved with technical task groups providing input to developing forest planning for the next decade. So it's very appropriate that Jim come in here when we're asking ourselves "Where Do We Go From Here?", and the decade is not a bad planning target.

So if you change the expressions from U.S. to Canadian terms maybe and just use it, but really his objective here is to help shape the changes in forest practice rules pertaining to riparian management areas.

DR. SEDELL,
U.S. FOREST SERVICE

Thanks very much.

Again coming towards the end here, I don't have a lot to add that Jeff and Vince and Pete haven't already covered other than to say again that I hope it continues.

And what I'd like to do is again acknowledge the profound effect the studies had in terms of shaping and reshaping forest practice policies in Oregon and Washington. It's been a pivotal study in that regard.

Another comment that comes out and follows along the lines that Jeff and Pete have developed comes from some of the diaries of the great river keepers in England and Europe; these were river keepers that had been watching rivers for forty or fifty years, and their sole purpose was for habitat management, because they ran these streams for large estates for some of counts and princes and whatever else of nobility that you've got here in the commonwealth - land of money.

But their comments after observation for forty or fifty years reflected really a concern for droughts; they weren't so concerned about the floods because they never felt that floods really depleted their populations. They were dealing with populations which didn't have a tremendous mix of anadromous fishes as you have here, and a lot of resident fish that could get big and you could catch them, but they were very much worried about the droughts.

And that plays very much into the work that Les Powell showed, this destabilization of channels, increasing riffles, increasing the channel volume at a given point in time which would make the stream all the more vulnerable to drought, whether it came as a result of less water or frozen water, a factor which we haven't keyed in on a whole lot.

Most of the research we've been doing has been concerned with flood effects and channel instability from flooding, and we're just now getting in, as Bustard has mentioned, the effects of drying periods, and I think that's an important one to keep going on.

The other concern is basin planning and landscape ecology, and really that's where the planning has to be over the next decade or several decades if, indeed, we're going to try to do both worlds of timber harvest and other resource management protection. And I refer specifically the question of how big cuts are we going to have?

We've got some very grand landscape experiments going on in the northwest with little postage stamp kinds of cut going on in the U.S. Forest Service land in which the cut doesn't get much bigger than 40-60 hectares versus large sub-basin watershed that in five years you get several square kilometers lopped off here in British Columbia.

And the question then becomes is what is the timing? I mean, we still have not answered the question whether it's better to go in incrementally with a lot of roads and enter an area repeatedly through time, or whether to get in and get out very quickly. And I think there are some very useful approaches to modeling this question. Blair Holtby has been the butt of a lot of jokes in terms of his modeling effort, but it is no joke.

The kinds of modeling efforts on landscapes they're doing at Harvard, University of Washington and Oregon State University start to look at what patch size is going to reduce wind throw vulnerability, which patch size is going to give, through decades of time, certain kinds of wildlife habitat characteristics or indeed if you're interested in fish habitat from big wood debris, what kinds of entry timing are you going to need?

Another timing question that has to be addressed again on a landscape, basin or sub-basin, follows some of the work Bob Willington and Dennis Harr have been playing with. You've got a transition snow zone in which it tends to precipitate a lot at point of origin for many of the debris torrents, and you get these rain on snow events which are very common in the coastal northwest. What percentage of the area per year in such a basin in such zones can be cut? That kind of planning has to be forward planning and deal with out of channel kinds of issues.

In fact, fishery biologists - to again push the call that Gordon was playing for earlier - are going to have to get involved with forestry and silvicultural issues. The issue just isn't in structures in the channel, the issue is very much a landscape issue and fisheries biologists are going to have to quit squishing the fish and get up and become geomorphologists and silviculturalists on the land, because that's where the game is going to be won or lost for my grandchildren. That's where the kind of advice that Grant was asking for will come from; we've got to get involved in that and be timely.

Another area of need is in the area of habitat management and habitat inventories, and there was a whole evening devoted to that. There is a tremendous effort in this area and in Washington and Oregon to try and consolidate inventory, try to come up with both intensive kinds of inventories and extensive kinds that will give you footprints that you can follow for several decades in terms of going back and evaluating how you are doing. What has happened? Those areas are important in terms of the timing of cutting and the amount of cutting kinds of issues; they are going to identify hot spots for different species at different life stages throughout the basin.

And while we tend to argue that all reaches of the stream are equally important for fisheries, it isn't true. There are some areas that are more equal than others, and those have got to be identified in the inventories.

Indeed, when you can hammer river systems like they have in Poland for centuries and then intensively in this post World War II industrial era, then when they cut the pollution and they cut some of the strange land use, the grateful fish come back. The grateful fish have been hiding somewhere, they've been finding some nooks and crannies, and we've got to start identifying them.

I'm not saying that we have got to reduce the fish to these nooks and crannies, but those are going to be the important areas to help us in terms of where the priorities are going to be, because fisheries' biologists are not going to get it all. We haven't yet, and we're not going to in the future. And so we're going to have to be careful in terms of where we start to locate our efforts, and it's going to be a much more landscape kind of issue.

Another issue is again the call for more long term study of sub-basins, and again the general problem that we've got in most work, in most of the synoptic work, is that we don't have enough of the long term data from which we can start to sort out natural variability from basically harvest management variability.

The data that was shown in the last couple of days from Carnation Creek demonstrates that very, very well. If it had fifteen, twenty years, those models might be very different, because maybe they could sort it out. Blair Holtby's model comes at a very critical time in terms of separating the response of the adults from some of the temperature issues that were going on in the stream. The long term record becomes extremely important in sorting out that kind of variability.

In particular what we're stuck with are areas in which we basically talk about logging effects or timber harvest effects, and it's really a surrogate for a whole bunch of kinds of effects from channel destabilization, road building, and what not, but we're not precise in terms of what's going on, and we just tend to lump everything in terms of timber harvest, and in that case we're going to need that long term data for recovery.

The last point I'd like to touch on is basically the interaction of applied research and basic research; we've heard a lot of talk over beer, and Grant certainly put it down as one of his top five, to get people out in the field interacting together, and then basically have some of the managers and operational people drive the research or suggest the kinds of research.

That process has to go on, but I submit that the success of the Carnation Creek study, as I see it, has been really a lot of serendipity. You had this venerable old rock in Scrivener being around as the continuity point, and you've had this crusty, old goat Hartman, that was brought in to jab around and pull it together and then very fortuitously and wonderfully they brought in the mouth, Blair Holtby, who was not a field person at all to compliment these empiricists.

This guy took the data and said hey, if we started to think about it this way, we could come out with some different ideas. I think the temperature stuff is very provocative, and it's going to be with us for a long time whether you believe it or not. It's the kind of stuff that science feeds on in terms of the mold as an architect and, in fact, a blueprint for asking questions and starting to tease apart the world.

If we've had anything in these models, and their presentation, it was a way to organize the world and take at a shot at it and say this is the way we think the world is working from this kind of data and these kinds of ideas. I mention this because it isn't a trivial idea.

We've got a lot of chaos in the brick yard out there. We've got a lot of bits and pieces of information that have come from dozens of places, and we have got bricks all over the place, and we have very few architects that know where to build it in a plan. And I submit that that model was an attempt to create some order out of the chaos that was surrounding a lot of forest logging kinds of stuff.

In terms of operational people driving research, there is indeed a good need for getting basic researchers out into the messy world of doing business in a sociological political context, but there is another view of basic research driving the managers. I bring out the large woody debris story, because when we first started to talk about large woody debris back in the early '70s, you couldn't get anyone in the forest service to think that it was a management problem. In other words, if management was driving research, we were going to be looking at temperature studies, sediments, gravel, and food - basically insects - and mostly water quality parameters.

Instead, a number of people kept going forward on this even though they got no support from either fisheries agencies or the land use agencies on this issue, and in effect broke open a story which then we've come around a decade later to try to incorporate into the way we do business on the land and with our fisheries.

So I point out that the freedom has got to be left within a study like this for serendipity, for basic science people; you can look at the big, successful companies around the world, and they've all left - unless they have had a cartel or monopoly - they have all left room for people within that organization to follow those leads.

And so Blair Holtby, my hat is still off to you, because I think you have done a valuable service from your basic research mode, and I think that when the Carnation Creek Study keeps going on, that it isn't just a series of data that you keep collecting, that you keep bringing in, that people will look at it differently even if it doesn't jive with anything that we're currently on track with, because those are the opportunities that are going to help us shape the next decade beyond.

MR. AINSCOUGH: Thanks very much, Jim. There's some good advice in there for us, and I'm sure that we will all ruminate, boil this down to the essence of some action plans all from our own perspectives, but let's hope that that's the real result. No light is going to come on suddenly and eureka, we're off on a certain course of action. All of us will take this from our own perspectives and we'll have a different "Where Do I Go From Here?"

But just before we get into questions and find out just what other people's feelings are about "Where Do We Go From Here?", I think it's very appropriate that Dr. Narver, the Director of Fisheries in the Ministry of Environment is here, the originator and supporter of the Carnation Creek project through close to two decades. He's forgotten more about a lot of these things than most of us know.

Dave, come up on and take five minutes.

DR. D.W. NARVER,
B.C. MINISTRY OF ENVIRONMENT

Do I have to? I never want to turn down the last word, particularly when I'm speaking last after Sedell. They shudder in their boots, I'm sure.

I'm an administrator now, and I do have that affliction of forgetting things. I think that goes with the territory. I think there is hope for administrators, because Gordon - I don't know if all of you know Gordon's background, but he went from a research biologist to an administrator in about two different organizations, both in British Columbia, the Fish and Wildlife Branch, and the Yukon, and there was hope for him because he came back and he was a research scientist again. Does that mean there's hope for me? I'm not sure.

There has been a lot of reminiscing and extremely good feeling in this audience like there was at Sandspit in the Queen Charlotte and like there was at the University of Washington last February. Any time these years that foresters, forest industry, and fisheries experts get together in the Pacific northwest all the way to Alaska, there is always good feeling - at least during the meetings. And I think in the field also there are increasingly good feelings.

I am extremely pleased and humble, I guess, that we were able all these years to nurture and maintain the Carnation Creek study. I suspect that to a degree it was more -- sometimes, I know, it was more good luck than good management, Grant, but these three days are a very real high for me personally.

I was telling several people that in 1970 and '71, '72, we had some growing pains and first conceived the program and got it going, but still didn't have all the structure in it that Grant was talking about. I would never, never have thought it possible that this meeting would happen 17 years later with all this enthusiasm.

But it really has been super, and I just want to assure everyone here including the people on my staff that my agency is going to continue to support the Carnation Creek work to continue integrated research and monitoring both at Carnation Creek and more broadly. We are committed, like I think most of the other agencies and the industry representatives here today are, to integrated resource management.

John Cuthbert, the Chief Forester of the B.C. Ministry of Forests and Lands, and I both spoke to the truck loggers yesterday on the panel of integrated resource management, and it was interesting. He and I had not compared notes of what we were going to talk about at least in any detail. We both dwelt considerably on Carnation Creek and that integrated resource research and the basis for management.

But I commit our agency, my agency, to both funding of this study and I think to that concept of communication, of beating the drum, making sure that integrated resource management, the application of the Carnation Creek and the F.F.I.P. results are, in fact, applied.

It was in 1970 when Grant, you insisted -- maybe '69, that we do a better job, and we set up stream inventory in the province, and Chamberlin and his federal counterparts are a long ways down that line now, and of course it's basic to the coastal logging guidelines.

Just one other thing that I'd like to say. I think that it's not enough to apply integrated resource management of streams and of watersheds, that alone is not going to recreate salmon and steelhead runs of historic levels, Never mind what the fishermen's union or the trollers say. For low stocks they always blame habitat. But for sure to get those stocks back we've got to be more dedicated not only to integrated resource management in the streams but to better fisheries management and better allocation.

Thank you very much.

MR. AINSCOUGH: Thanks very much, Dave.

QUESTIONS
SESSION 6: SYNTHESIS

Moderator: G. Ainscough

DR. HARTMAN: I have a question, I think, that may be directed to Mr. Ainscough, perhaps to Bill Young. I think that in the discussions you've heard here that you recognize that in order to understand some processes and in order to understand some kinds of impacts, there's a need to have a long time series of information, which means that if we are as fisheries research people going to have the information that you would like ten or fifteen years down the road, we should perhaps be starting by aiming at that objective right now.

And so the question I've got for you people is this: How much advice can you give us about the types of situation that the forestry industry will be in fifteen years from now? Are we going to have an industry that is concentrated in second growth areas or 80 percent in steep slope or will you have gone over into making lumber out of shredded fibres or something?

I'm being a little facetious here, but what sort of mix of situations are we going to be in? I think if we understood that better, then some of the long term work that's planned might be planned more intelligently, but we can't look into your crystal ball at all, but could you? Thank you.

MR. AINSCOUGH: That's a terrific question, Gordon. I don't know where to begin to answer it except to say this, that to the extent that we have the ability and the tenure and long term outlook, the industry and the forest service are trying to make 25 year development plans so they can form the basis, and in the reviews and annual reviews of plans, the habitat managers can certainly get together and anticipate the direction in which the developments are going to go.

They will be good enough for general direction, because you know what's happened since December 30th. You've got to be a little bit fast on your feet and flexible. Things are going to change, but the principles I don't think will change, and we can contribute certainly to the kinds of things that we feel are needed for habitat management. But I think again the people who pick up their pay cheques as fisheries habitat managers have got to be the focal point of where the emphasis should be on research.

But if it's like silviculture, for example, if we shut it down tomorrow morning, didn't do any more research for several years, every one of those research people could be usefully employed in technology transfer and getting out in the field and working with the people out there with the problems using their skills and their specialized knowledge.

So maybe there's a greater emphasis on technology transfer or boiling things down into practical terms for the forest land manager, and maybe even for the habitat manager who may not speak your language at all.

MR. HANDLEY: I haven't got the question written out, but I want to make a statement, although let me first of all continue the answer to Gordon Hartman. I think the answers to Gordon Hartman are going to be all of the above. We're going to be working in all those situations for the next century, and just keep going, so don't try and compartmentalize.

What I'd like to try and do, and I'm a slow thinker so bear with me, is look back on what's happened since we started here and since Carnation Creek started, and not to be too bound up in the individual detail results. It really came home to me when we were entertained last night by that very serious side show, and we saw what was happening in the late eighteen hundreds and early nineteen hundreds, and ultimately I'm going to have a question for Jim Sedell and perhaps Jeff Cederholm might also respond.

We have been playing around with stream habitats for the last century here in British Columbia. Rosewall Creek was mentioned yesterday as a source data on, I think Blair said, coho returns. I don't think there's a creek on the island that suffered worse than Rosewall Creek when it was logged. They did everything they could to exterminate that fish run, and yet there's still fish there.

My question to Jim and to Jeff is considering all the other variables, considering the resilience of fisheries and all the other processes, and again for those of you who don't know me, it's not that I'm wanting to say we should go back and practice the old methods, far from it, but what I want to try and get is a feeling of balance, can we over balance ourselves in trying to protect watersheds that we cannot protect?

DR. SEDELL: Yes, I think it's a valid question. There's no question but when look world wide at management impacts on streams and rivers that you can't see an improvement in terms of overall fisheries regardless of what fishery stocks are. I mean, we can see little bits of pieces going up through time, and it boils down to -- I agree, there's a lot of hand wringing and in a way we're caught in a tobacco industry kind of argument as to whether, in fact, smoking causes cancer or maybe it's your spiritual well being or whatever that keeps you from getting cancer. Anyway, there's this whole cancer kind of tobacco industry where you can't see the direct cause. There's a whole multiple cause.

And we see naturally tremendous disturbance features that have gone on that far overwhelm the kind of logging impacts that we've seen. I'm looking at vulcanisms, the period of vulcanism up and down the Pacific Rim would be one. Also there have been tremendous floods. The Columbia River system had tremendous floods eight or nine times over the last sixteen thousand years, and, my God, those floods dumped boulders as far up, you know, ninety miles up into Corvallis. I mean, we haven't experienced those kinds of natural disturbances.

But it boils down to where we do have a choice, it really boils into a stewardship issue with regards to the data, and it boils down to the old argument of keeping options open. The timber industry has got the same problem of going to total fibre utilization and chips and resin for wood when big structural wood is pretty well gone, and we're going to other kinds of wood characteristics with faster growing species. Are they locking themselves into certain markets in fifty, sixty years?

I think that most of what I've seen is basically a genuine concern and an appropriately put concern to keep the streams from getting truncated from the forest and try to minimize those impacts on the streams. I don't see that over the next fifty years we are going to rehabilitate that many streams, but I do think the efforts that are going on now are certainly going to be enjoyed by my grandchildren's children, and, in fact, that's where we've got to keep approaching the land.

DR. CEDERHOLM: I guess what I would add to that statement by Jim is that I've been working on a river system south of here where we are looking at both ends of things. We're looking at the anadromous fish and they use the ocean and they use the fresh water environment.

Many of the people here today are involved with the end of the scale where they're in the fresh water environment, spawning and rearing habitat. People who aren't here today, are harvesting those fish in the ocean; when they don't come back to our streams, we never see them again. We put out these smolts, and we don't see these fish return. That group of people are having a tremendous impact, and Dave Narver touched on that in his presentation.

I guess what I would say to the question of Dave Handley is that it's a combination in this real world we have today. It's a combination of impacts. There is heavy harvest, an industry that is going to continue and probably going to grow in numbers and in efficiency in the future. If anything, it needs to be moderated, but those kinds of industries seem to perpetuate themselves, in my experience, and then you start getting into artificial production and all the problems of mixed stock fisheries. What it all boils down to is a greater and greater impact on our natural stocks.

Our natural stocks are the backbone for our fishery. We need to protect them, and if we don't protect the stream environment, we're not going to have natural stocks. And when we put all our emphasis into artificial stocks, it's just a matter of time when they begin to fail, because man can't consider all the intricacies of salmon life history and cover for himself in a hatchery. Disease problems constantly come up and water quality problems arise, and eventually the stocks will dwindle to nothing.

So it's a combination of impacts, and even though sometimes we think our efforts are futile, believe me, we need to maintain these natural stocks, and that comes from wise watershed management in the small tributaries as well as the large river systems in doing a few of the things that we have learned from this workshop and others to hold up our end of things, and hope that the people who are in power recognize the two ends of the cycle and moderate that fishery. That's where we really need to put an emphasis in the future.

MR. AINSCOUGH: Thanks, Jim.

There's one area that hasn't been referred to, at least not in much detail this morning, and that's the structure under which we would operate. We 've got very divided responsibilities between agencies, industries and so on. The greatest success in Carnation Creek, I think, if you want to point to one single thing was getting all these various players together in a cooperative project, making their commitments, and then following through with them.

But we've got a senior steering committee of forest industry and deputy ministers of the agency that's dealing with the fisheries guidelines. The only way we ever got comfort that Carnation Creek was going to get off the ground and stay off the ground was to get the coordinating committee with some honchos from the agencies who could sit down and commit those people to the program.

Ultimately somebody will have a comment about structure and what they see from that as a beginning.

MR. DE LEEUW: My name is Dionys de Leeuw from the Queen Charlottes Islands.

Society in the Charlottes tends to be rather polarized between forestry and fishery and natives, and the question I have is a rather broad one, and it's directed at Jim Sedell and Jeff Cederholm. And my question is this: How important in the United States do you think that changing societal ethics rather than straight science has been in the overall improvement of environmental management? If you don't want to answer it, you don't have to.

DR. CEDERHOLM: Nice question there. Societal ethics, right?

MR. DE LEEUW: Right.

DR. CEDERHOLM: I guess one of things that rings a bell there in my mind is in the State of Washington we had in 1974 the Bolt decision, and prior to that time I would say that our real fisheries management was on a cul-de-sac. It was going in the direction of hatchery production being the key factor and natural production, in my opinion, was not really emphasized as much as I would like to have seen it. And we really did not grasp what the stocks could handle in terms of harvest. We were in a quandary at that time.

The Bolt decision came along, and it basically gave the tribal people, the native people, a say in the harvest, a say in the management and a portion of the harvest. Then what came off of that was it also eventually led into their say in watershed management and gave them a hammer over the agencies including my agency, the State Department of Natural Resources, the Fisheries agency, and others.

I have just completed this T.F.W. process on redoing our Forest Practices Act, as I mentioned earlier, and I'll tell you without that hammer, that threat of suits by the tribes who have the best intentions in mind for our natural populations, I don't think we would be as far as we are. They are reminding us of how important it is to recognize and maintain the integrity of our natural systems and populations of fish.

DR. SEDELL: In terms of society, I mean, let's face it, the technicians like most of those people, myself included, that we've heard in the last two and a half days aren't going to drive the issue. I mean, the information gathered at Carnation Creek, Clearwater, the Andrews Forest in Oregon and whatnot isn't going to make a pinch of difference in terms of what society decides.

There's going to be a whole bunch of forces, legal and social, that do that. I mean, that decision is going to be made by people - hopefully people of goodwill - that are up front.

Where this information comes in is once people decide that fish and forestry are both important, how do we do it well; or if we're going to emphasize this part of the resource over the other part of the resources, then certainly the information that we started gathering in Carnation Creek and elsewhere becomes an important part in terms of shaping just exactly the kinds of things we do. But in terms of the ultimate decision, I mean, the power brokers up there hopefully are people of goodwill.

In Oregon we rode the coattails of the Indian issues also, but one of our big changes in the last ten years has been a big demographic change, big influx of population from outside the state whose cousins and brothers never were in the timber industry, and so they don't relate to the old choker setters, and then just the economics of the industry has changed. So those kinds of factors play a big role.

MR. DEHART: My name is Darcy Dehart. I'm a district manager with the B.C. Forest Service.

We've had a lot of information here in the last couple days, some of it contradictory. I'm just wondering now that papers are going to come out whether somebody is going to stick them away in a drawer or shredder or whatever they do with the papers. I'm wondering if that's the end of this information flow or is there a plan? And I think it's part of the fisheries agencies' job now to take the best information available and somehow get it out to the field decision makers both in industry and the agencies in some form. I think this communication has to happen.

Forest/fish guidelines are coming out. Even for that we have to have informed people to properly interpret and apply them. So I don't know if it's a statement or question. What's going to happen? How is the information going to flow now, or do we just go home?

MR. AINSCOUGH: Darcy, speaking as a forest land manager and with not only a mandate but commitment under the Forest Act to do it, I guess one specific part of this we were talking about earlier.

But I think specifically to Carnation Creek, if I can just narrow it down to that, Darcy, I'd like to invite Gordon to make a comment if he would.

DR. HARTMAN: I wanted to get some reaction from you. How much use you thought you had got from the proceeding from that first conference, recognizing that it was an overgrown progress report. We had it made up for almost nothing, but we had a lot of copies sent out to divisional forest offices and ministry of forest offices and so forth, and the real objective when we put that thing out was to aim it out into places just like your office.

So I guess I would be curious to know what happened to it? When you got it, did it go on a shelf or did your people look at it? Because that was about as far as we could get the thing. We could have sent more copies out, if people had wanted them, but we thought we had given it our best shot getting it out to you.

So I turn the question around, did your people read it? Was it readable or did you think you should have something else?

MR. DEHART: That question is to me? I haven't seen it for a long time, and I don't know what's happened to it. Maybe it needs updating. I haven't referred to it or found it, like I say, in the last few years myself. I haven't had a cause to look for it.

MR. AINSCOUGH: I guess that's one byproduct of this, that when these guidelines are finally embossed and printed and produced we will have the benefits of our discussions today and to help us to read them and understand where they really are hardened off and where there are guides that cause you to think a little more as you're planning.

We'll take yours as the last question then.

MR. FRASER: I'm Jim Fraser, Whistler Department of Fisheries, and I'd like to give my perspective of what I've gained at this conference.

I see some real excellent things and I see some disturbing things too.

As a habitat manager, fisheries habitat manager, simple management needs again reaffirmed and those are obviously that a buffer strip is needed - we've known that for many years. I think preventing disturbance to streambanks and unique habitats, has been real good information.

There's a challenge though, I've got here, and a disturbance for the future. Many areas along the coast, it's been alluded to, are getting into steeper areas, and the gentleman who worked on the Queen Charlottes alluded to that. I haven't seen the results of his research, but he indicated there's a real problem in that area.

I see it in where I work, and for a large percentage of these steep forested areas what I've seen is basically any nick or cut, any disturbance, will have a high potential for eventual damage by debris torrents which change the stream morphology. That came out of this conference to me pretty clear too, with the adverse effects on fish production.

So we're getting into a little new area there. I don't think there's a great cost to industry for the direct work gained from Carnation Creek. I don't think it's a great cost to society for a buffer strip and minimizing the disturbance to the stream directly. But as we get away from it, to the smaller and steeper drainages, I think we've got a problem we've got to face in the future. It already exists in many areas, and considering the macro mitigation that will be affecting these areas, I think there's a cost to society that we've got to face up to.

In simplistic terms as a practical matter this may mean a lower rate of road building and maybe no road building in certain areas. That obviously has great implication on the rate of cut. This has a cost to society. I think this is an area we need to look at in the future.

CONCLUDING MESSAGE

MR. AINSCOUGH: Thank you very much everyone for your participation, for your commitment and interest. I happily now will turn the microphone back to Bill Young. He has some summing up to do.

CONCLUDING MESSAGES BY BILL YOUNG, GENERAL CHAIRMAN

MR. YOUNG: Thanks, Grant, and to your panel.

As chairman of this session, I've got about ten messages here that I quickly will run through, and I'm going to follow up on them, some of them, maybe all of them in appropriate letters to whoever the proper source is, but let me go through these messages I've got in no order of priority and of importance:

1) I got the message that Carnation research results should be packaged some way in an integrated sense so they knit together for the practitioners;

2) I think there's a recognition that researchers provide results on how a system works and should not be expected to develop forest harvesting guidelines, and we shouldn't expect them to nor should we ask them to;

3) Notwithstanding that comment, researchers do have responsibility though technology transfer in communicating research results that should be brought together;

4) Managers in the public and private sector have the prime responsibility of taking forestry/fisheries research results and incorporating practical or economic facts of life and transfering these results into operational fisheries or forestry plans, whether they're field trials, managing riparian zones, or whatever;

5) It is important to maintain the Carnation Creek project in some type of phase two development stage or project with possibly new objectives over phase one, and especially since the recovery phase in that stream is still ongoing. Why? Because I think it's a guidance, a continued guidance to forest operations in British Columbia. I think it's of guidance to population management of fisheries in British Columbia, and as some of our U.S. cousins said, a contribution to the scientific community of knowledge itself;

6) The next one I have is phase two, and contrary to what my friend Peter said, phase two should not involve artificial rehabilitation projects. There's lots of streams we can develop as artificial rehabilitation projects; we should let Carnation Creek continue in a natural stage in its rehabilitation as trees continue to grow and channels continue to stabilize and so forth.

7) The next message I have is the importance of advancing the processes of habitat inventory and habitat management;

8) And another, the importance to address the rate of cut in specific watersheds. I know some meetings have been going on in this hotel, but that came up time and time again, the rate of cuts in specific watersheds. There's some political aspects, which I think is a good message, we've got to get the policy in place, because policy declaration is a green light to action. So let's get the policy in place, through the senior managers of agencies with their private counterparts.

9) Another message I have, there are interlinkages and common denominators between the Carnation Creek project and other forestry/fishery assessment research type projects going all up and down the coast in both countries.

10) Also, notwithstanding that fact, activities should be developed for extrapolating Carnation Creek findings up and down the coast.

So I, on your behalf, would like to develop that over the next week or so and offer some friendly advice to the appropriate groups from someone who doesn't fear anybody these days.

Finally I think I am convinced there is a sincere willingness by the forestry and fisheries' practitioners just demonstrated in this room to work towards integration of forestry and fisheries management in coastal B.C. I might say that's 80 percent of the battle, and surely it's not impossible to overcome the final 20 percent.

Again just before I turn it back, just a little bit of my philosophy once more. British Columbia and the adjacent areas, especially in Alaska and the adjacent state just over the line, is topographically, climatically, and resource wise probably the most diverse forest ecosystem at least in the developed parts of the world, especially the timber producing countries of the world. I think that diversity brings us a quality of life such that we look at the Pacific northwest as the best place in the world to live, but that quality of life and that feeling comes with a heavy burden, and that burden is that diversity equates with complexity in integrated resource management.

As Gordon Hartman's message said, don't look for simplistic solutions in Carnation Creek, or for that matter in any part of integrated resource management research or programs in this part of the world.

APPENDIX 1:

RESEARCH AND FORESTRY - FISHERIES MANAGEMENT: INSTITUTIONAL VOIDS IN TECHNOLOGY TRANSFER

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INTRODUCTION

The following are some thoughts with which I have been left after two workshops and six years of forestry-fisheries research. I did not express these ideas at the January, 1987 workship in Nanaimo.

THE WORKSHOPS

There have been two Carnation Creek workshops, one in February 1982 and one in January 1987. Both workshops were aimed at managers on the forestry-fisheries interface. Both were attended by about 270 people. There is clearly a strong desire on the part of resource managers to gain information from the Carnation Creek project.

The technical papers in the January 1987 workshop attempted to bring managers up to date on the project, and most papers were good research presentations. Several of the panelists, however, indicated that they had problems with technical detail and interpretation. Many of the participants wanted the results condensed and simplified even further than they were. Some of the panelists misSinterpreted the results and conclusions from the papers. This may not be surprising because some of the papers contained a great deal of very condensed but complex material.

The presentations on the last morning of the workshop were intended to review and integrate the research results, and to discuss their application. Although this session was stimulating and prompted discussion, I think that it, and the workshop as a whole, still left us asking - where to from here?

Where Do We Go From Here?, The Continuing Question.

We are still asking this question and worrying about the lack of application of research work not because there is research failure but because there is an institutional void for research information transfer. In all of British Columbia, only a small number of people are working on forestry - fisheries research. In DFO, at the Pacific Biological Station, people are required, first and foremost, to publish material in primary fisheries journals. Practising managers are not viewed as the highest priority clients for research. Recognition is based primarily on publication counts not on effort to deal with field level managers.

In other agencies, staff have many responsibilities besides working on the Carnation Creek project. So, in spite of good intentions on the part of the Working Group, only a few people are able to push a small number of publications out into a no-mans-land between the disciplines of research (long and slow) and management (fast moving and under pressure).

Managers, particularly those with a forestry background, cannot easily find out what kind of fisheries research is being published.

They cannot easily obtain this material and read it if they do hear about it. It is clear that they cannot effectively reach out into the no-man's-land, get the information and develop a required understanding of complex system processes. However, that is what they need if they are to participate seriously and effectively in integrated land use management.

Two Day Workshops Won't Do It.

Two day research workshops are useful notices of what has been done. Two day training sessions at the outset of the implementation of new forestry-fisheries guidelines will be valuable introductions to the guidelines. But in the context of understanding, even the key forestry-fisheries research work, and beginning to apply such understanding in the complex process of planning and decision making in diverse basin systems, two-day workshops are analogous only to the introduction of a couple before they begin to dance.

BRIDGING THE GAP BETWEEN RESEARCH AND MANAGEMENT

The forestry-fisheries interface is a major area of interaction in British Columbia. Integrated land-use planning has been put forth as a major commitment by governments. Notwithstanding this, no serious effort is being made to bring people, who are "out there on the ground" in "the real world", up to speed.

There is a need for substantial education processes at the forestry-fisheries interface. There is also need for institutional structures to carry out the education processes. These structures should fill the no-man's-land between research and management. They should draw the ideas and the work results from the research people. They should clarify it, where necessary, simplify, where such can be done without loss of meaning, and amplify it so that it reaches the hundreds of managers from Prince Rupert to Vancouver.

RECOMMENDATIONS

I will offer some recommendations. They may not be well organized but they may stimulate further action:

1. Establish a major program for field level forestry-fisheries education.
2. Put together a group of educators who can communicate with research workers, draw together papers, prepare courses and workshops in-house and do extension presentations at work sites.
3. House the program in a community college where there is already an active forestry program.
4. Keep the existing diploma programs separate from the field program but organize them to complement each other.
5. Don't kill the program before it ever starts by trying to do it for nothing.
6. Organize courses (in-house and extension) that are targeted at different types of problems and at different levels of managers.
7. Structure the program so that it permits and encourages a two-way flow of ideas and information. It is important that this program, if developed, does not assume a 'we will tell you how' complexion.
8. Structure the program so that participants can keep coming back and building upon what they have learned before.
9. Teach participants the fundamentals about hydrology, soils, plant ecology and fisheries so that they understand processes within drainages.
10. Review in some detail the major forestry-fisheries studies that have been done from Oregon to Alaska.
11. Start now!

I have listed 11 suggestions. They represent my perceptions of need, not specific imperatives. My last suggestion is that a group, drawn from government, industry and the academic community, be establisjed to discuss the idea of new education and training initiatives. If they see merit in the idea of such initiatives they should take steps to have them funded and implemented.

The Need For Commitment

The type of program that is required to bridge the gap, from the output of the scientists to the needs of the managers, will not begin if government is not committed enough to integrated forestry-fisheries planning to pay for these educators and facilities. This type of program could be carried out with three or four people and modest support equipment. It need not be prohibitively expensive. The program will not succeed if the forest industry and governments are not sufficiently committed to bear the cost of having their staff off the production line long enough to profit by the program.

I suggest that if there is not real commitment to appropriate levels and means of research and education transfer we will see a few research workers continuing to communicate with the scattered managers whom they know. We will see most land managers continuing to complain that they don't get research results, or can't understand them if they do get them. We will see government and industry, forestry and fisheries, trying to carry out land management on a diminishing resource base, in progressively more difficult sites, with dedicated but not necessarily up-to-date people, most of whom have limited and unchanging skills.

APPENDIX 2:

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